SATELLITE SYNTHETIC APERTURE RADAR IN THE PROSECUTION OF ILLEGAL OIL DISCHARGES

SHERRY L. McHUGH

SATELLITE SYNTHETIC APERTURE RADAR IN THE

PROSECUTION OF ILLEGAL OIL DISCHARGES

by

© Sherry L. McHugh

A thesis submitted to the
School of Graduate Studies
in partial fulfillment of the
requirements for the degree of
Master of Arts

Department of Geography
Memorial University of Newfoundland

May 2009

St. John's Newfoundland

ABSTRACT

Illegal oil discharges from ships are a problem that affects the world's oceans. Aircraft has been the main surveillance method since the 1960s; however, the advent of earth observation satellites offers many advantages over this traditional technique. In the past, oblique aerial photographs and optical satellite imagery have been used as evidence to prosecute illegal discharges; but satellite Synthetic Aperture Radar (SAR) imagery has not been used as frequently. During this thesis research, the legal challenges of using remote sensing as evidence in the prosecution of illegal oil discharges were investigated. A review of the legal literature revealed two limitations on the use of remote sensing within a legal context, which included the admissibility and authentication of evidence. The admissibility and authentication of satellite SAR imagery and oblique photographs as evidence in the prosecution of illegal oil discharges were the focus of this research. Expert witness qualifications and the reliability of the two methods were outlined to address admissibility. All of the elements of the image interpretation used in the identification of oil slicks using oblique aerial photographs and SAR imagery were compiled to address the legal requirement of authentication. In addition, standards were shown to be used within each remote sensing method. A case study using a RADARSAT-1 SAR image and oblique aerial photographs from an oil pollution incident off the coast of Newfoundland, Canada, was used to illustrate the legal chain of custody and how these data can be presented as evidence. The results from this analysis revealed

that there are no technological barriers to satellite SAR images as evidence in court for illegal ship discharges when used in conjunction with oblique aerial photographs.

ACKNOWLEDGMENTS

This thesis research would not have been possible without the support from several sources. First, my husband, Chad, and my step-son, Nicholas, who sacrificed many nights and weekends: I am grateful for their love and support. Second, I would like to thank my supervisor Elizabeth Simms (Memorial University, Department of Geography) for her patience, continued support and guidance during this research. I would like to thank my other committee members, Randy Gillespie (Marine Institute, School of Ocean Technology) and Moira McConnell (Dalhousie Law School), for their help and guidance. Also, Robert Currie, a Dalhousie Law School professor provided additional background information. There are many C-CORE colleagues I would like to acknowledge, especially Carl Howell and Thomas Puestow who provided technical advice and Desmond Power and Charles Randell who provided a flexible work environment and financial support through dedicated work time. I would like to thank all of the I-STOP partners, especially Joe Pomeroy (Water Quality Monitoring Atlantic) and Wayne Turpin (former Chief of Enforcement) with Environment Canada, who were instrumental in sparking my initial interest in this topic. Also, the Canadian Space Agency and I-STOP partners for providing the RADARSAT-1 imagery and other associated data. I would like to thank Jeff Hurley of MDA Geospatial Services, Gerry Mallard (Canadian Coast Guard) and Louis Armstrong (Transport Canada) for their support and answering all of my technical questions concerning their operations. Last, but not least, I would like to thank the members of the Environmental Damages Fund (EDF), who provided funding to conduct the background research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADAM	Airborne Data and Acquisition Management
BAOAC	Bonn Agreement Oil Appearance Code
CanLII	Canadian Legal Information Institute
CARCH	Canadian Archive of RADARSAT-1
CCG	Canadian Coast Guard
CD	Compact Disk
CEOS	Committee of Earth Observation Satellites
DN	Digital Number
EPA	Environmental Protection Agency
ERS	European Remote Sensing Satellite
FLIR	Forward Looking Infrared
GIS	Geographic Information System
GPS	Global Positioning System
ISO	International Organization for Standardization
I-STOP	Integrated Satellite Tracking of Oil Polluters
ITOPF	International Tanker Owners Pollution Federation
LIDAR	LIght Detection And Ranging
MARPOL	Marine Pollution 73/78
MDA	MacDonald Dettwiler and Associates Geospatial Services
MPIRS	Marine Pollution Incident Reporting System
MSC	Meteorological Service of Canada
NASP	National Aerial Surveillance Program
NEES	National Environmental Emergencies System
PPO	Pollution Prevention Officer
SAR	Synthetic Aperture Radar
SOPs	Standard Operating Procedures
TC 211	Technical Committee 211
UTM	Universal Transverse Mercator
WorldLII	World Legal Information Institute

1 INTRODUCTION

For much of the last century, the degradation of the world's oceans from ship operations has been recognized as a major concern. Oil from ships can enter the water through large accidental spills or through small spills caused by malfunctioning equipment, negligence, or illegal actions. The total estimated volume of spilled oil from large accidents is less than that released from illegal "operational" discharges which originate from tank washings, dirty ballast, and bilge pumping (Oil Spill Hazard Team, 1997). Illegal oil discharge accounts for more than 45 percent of the world's marine oil pollution (Petrocchi, 2000). The main visible indicator of these illegal discharges is the large number of dead or dying seabirds found along shorelines around the world. Most of the documented research has occurred in Canada, Scandinavia and in the Mediterranean region, which have some of the busiest shipping routes in the world. However, the illegal discharge of oil from ships into the world's oceans is a problem that affects the entire marine ecosystem (Wiese, 2002).

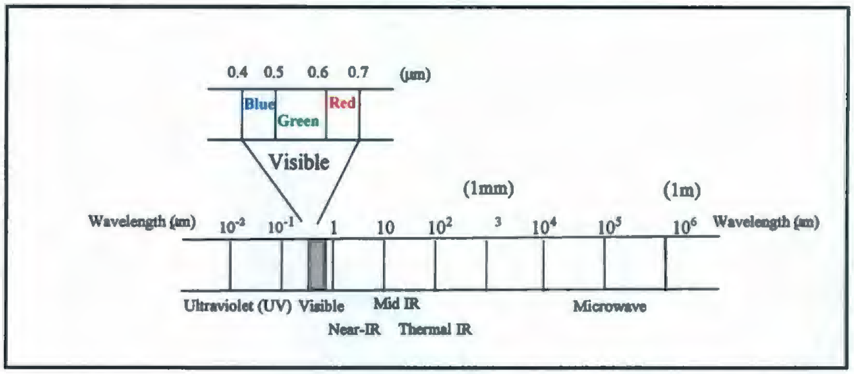
The international community first addressed illegal discharges in the 1930s, when several maritime nations agreed to develop measures for oil pollution in the ocean. In 1954, the first international convention was held in London on this topic; however, it did not deal with enforcement issues concerning this pollution at sea. Almost four decades later, the international community reached an agreement at the International Convention for the Prevention of Pollution from Ships called Marine Pollution 73/78 (MARPOL 73/78) (Pavlakis *et al.*, 2001). This convention introduced standards that only allowed oil to be released certain distances from land and in very small amounts. Under MARPOL 73/78, the highest legal concentration of oil that can be released into the ocean is 15 parts per million (ppm), which is achieved by running bilge water through an oily-water separator before disposal at sea.

1.1 Remote Sensing of Oil Discharges and Spills

From the moment oil is discharged into the ocean, it continually changes both in shape and chemical properties. These processes are known as weathering, which involves spreading, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation (Jordan and Payne, 1980). For ship discharges, the first few hours are the most important for monitoring purposes, due to the rapid interaction with seawater (Pavlakis *et al.*, 2001).

The discipline of remote sensing is the gathering of information about targets of interest from a distance, such as aircrafts and satellites, which is achieved by measuring the amount of electromagnetic energy emanating and received from those targets (Lillesand and Kiefer, 2000). Remote sensing systems are broadly classified into passive and active sensors. Passive systems record the solar radiation reflected or thermal radiations emitted by the earth's surface and therefore rely on a source of energy external to the sensor. Active sensors emit energy and receive the proportion of that energy backscattered by the target of interest. Passive sensors include panchromatic and multispectral systems. Panchromatic sensors are sensitive to a single wide spectral band of the visible (Figure 1-

1) and are considered the digital equivalent of traditional, black-and-white aerial photographs. Multispectral systems relate to colour photographs in that they record simultaneously with more than one spectral band.



(Modified from Lillesand and Kiefer, 2000)

Figure 1-1 Electromagnetic spectrum

Traditional surveillance techniques conducted by national governments to monitor illegal oil discharges have included airborne and ship-based methods which use panchromatic, multispectral sensors and film camera. However, the advent of satellite remote sensing in the early 1990s has improved capabilities, providing 24-hour all-weather surveillance.

Aerial photograph interpretation can be used to detect oil slicks. However, optical systems such as these have limited detection capabilities for oil spill surveillance, mainly due to their sensitivity to fog and cloud. Aerial photographs are usually classified as either vertical or oblique. Vertical photographs are obtained when the camera's axis is within ± 3° of nadir (Jensen, 2007). In oblique photographs, the optical axis of the camera is inclined more than 10° from the vertical, which produces a changing scale across any given frame (Reeves *et al.*, 1975). Synthetic Aperture Radar (SAR) satellites collect oblique-view images from incidence angles typically between 20° to 70°.

SAR, LIght Detection And Ranging (LIDAR) (Feigels and Kopilevich, 1996) and Sound Navigation and Ranging (Le Chevalier, 2002) are active remote sensing systems. The imagery generated by a SAR system is a visual representation of microwave wavelength electromagnetic energy backscattered by the target of interest. Although SAR images look like black and white photos, they are in fact very different. SAR does not rely on the sun to provide illumination and can therefore acquire imagery day or night. In addition, the microwave radiation used in SAR sensing is minimally affected by haze or cloud-cover due to the fact that the size of the radar wavelength is smaller than these haze or cloud particles in the atmosphere. This quality is particularly desirable in areas that are characterized by significant levels of cloud cover throughout the year. The capabilities of SAR to detect oil spills on the sea surface, as well as to survey large areas independent of sunlight or cloud coverage, make it an ideal complement to traditional optical surveillance techniques. The visual identification of oil slicks with satellite SAR relies upon the ocean's surface backscattering, which is dependent on the sea state. Radar can detect oil slicks since oil smoothes the sea surface, reducing the amount of energy backscattered to the satellite.

There is a possibility that oil slicks interpreted on SAR satellite imagery may in fact be other features on the surface of the ocean. Unequivocal oil slick identification requires visual inspection. Satellite SAR has been used to locate and identify oil slicks since the early 1990s; however, according to recent studies (Robinson and Ufermann, 2003), objective validation still awaits the gathering of sufficient independent records of oil slick occurrences. The Marine SAR Analysis and Interpretation System project in Europe attempts to promote the use of SAR data of the ocean to non-experts and to ensure that the SAR applications are developed beyond the experimental demonstrations and become operational for routine monitoring such as shipping, offshore engineering, and marine pollution control. Through this program, it was determined that the calibration and validation of some marine applications, such as wind speed and waves are more established than oil slick detection. The lack of oil spill events for validation may impact the use of satellite images in court.

Aerial photography is often used in pre-trial settlements and court cases to increase visual comprehension. In most court cases in Canada, where aerial photographs have been entered into evidence, vertical aerial photographs have been used. However, the majority of legal cases involving aerial photographs as evidence has been civil and boundary disputes, whereas illegal oil discharges are in the category of environmental offences, which are generally described as regulatory or public welfare offences (Benidickson, 2002). In Canada, the *Fisheries Act (1985)*, *Canada Shipping Act (2001)* and the *Migratory Birds Convention Act (1994)* are applied when illegal oil discharges are brought to court. High oblique photographs captured from the aircraft's window during oil pollution surveillance flights have been used as evidence in the prosecution of illegal discharges, while satellite SAR data remained under-exploited.

Two limitations identified in the literature on the use of remote sensing within a legal context include the admissibility and authentication of evidence. The admissibility and authentication of satellite SAR imagery and high oblique photographs as evidence in the prosecution of illegal oil discharges are the focus of this thesis research. Admissibility is when evidence is permitted to be used in court, the competency of the expert witness and the reliability of the data are illustrated. Authentication is establishing the identity of the evidence submitted in court and assuring that appropriate standards are applied in collecting of the evidence.

1.2 Objectives

Based on the limitations stated in the legal literature concerning the use of remote sensing as evidence, the following objectives are developed. The first objective is to investigate the challenges of using remote sensing as evidence in the prosecution of illegal oil discharges. Some of the legal parameters associated with using remote sensing as evidence are be outlined, while the use of aerial photography as legal evidence are investigated. The comparison of aerial photographs and SAR provides insight into some of the legal parameters that may need to be addressed in order to use SAR imagery as evidence.

The second objective is to prepare the technological parameters for the validation of SAR images to be used as evidence in court. When oil is detected on a SAR image, ground verification is needed to determine that it is a real slick due to the high false alarm rate associated with oil slick look-alikes.

A false alarm (i.e. an error of commission) is when an "oil slick" is detected that is not really an oil slick, but an oil slick look-alike. An error of omission is when an oil slick actually occurs, but it is not detected. This is a harder type of error to quantify, and there is no way to determine the number of oil slicks that will be undetected. The consequences of detecting false alarms on SAR imagery include wrongful criminal charges and time and money wasted for surveillance resources to validate the oil slick using an aircraft. Some of the parameters that affect the detection of oil on a SAR image include surface wind conditions and sensor characteristics such as wavelength, polarization, incidence angle, spatial resolution and weathering of the slick. In addition, there are other factors, such as oil type, amount of oil released, as well as physical, geographical and geometrical parameters, that affect the identification of oil slicks on the ocean. A step-by-step procedure to validate the image analysis, linking the legal requirements, is needed such as the legal chain of custody outlining all activities from image to the final image product. All of the technical steps conducted during the remote sensing process have to be properly documented for legal use and ensuring that these steps are the standard methodologies accepted within the discipline and legal rules of evidence are applied.

The third objective is to propose an approach to establish the authentication of satellite SAR using existing legal and remote sensing guidelines. This will link SAR standards to existing legal guidelines for oblique aerial photographs and help in the preparation of satellite SAR as legal evidence.

The outline for the research includes a review of background literature addressing remote sensing methods used within a legal context and examples of aerial photography and satellite imagery used as evidence in court. From this review, the limitations of using remote sensing as evidence are revealed. These include admissibility and authentication, which are addressed in the thesis. Standards are presented for each remote sensing method, including expert witness qualifications and reliability of the method to address admissibility. In addition, the elements of the image interpretation used in the identification of oil slicks using aerial photograph and SAR imagery are compiled to address the legal requirement of authentication. A case study using a SAR image and high oblique aerial photographs from an oil pollution incident off the coast of Newfoundland illustrates the issues related to the chain of custody from a legal perspective and how these images can be presented as evidence.

2 REMOTE SENSING USED WITHIN A LEGAL CONTEXT

Remote sensing technology has been used in litigation mainly for documentation of conditions over large or inaccessible geographic areas, to detail reoccurring conditions or to provide a synoptic view of conditions normally recorded by traditional evidence (Latin *et al.*, 1976). It has also been shown as a valuable tool in environmental monitoring and law enforcement. During the 1970s, the U.S. Environmental Protection Agency (EPA) began to actively pursue remote sensing in law enforcement related activities (Latin *et al.*, 1976).

Even though satellite SAR's ability to detect oil has been demonstrated for more than a decade (Bern *et al.*, 1993; Pellemans *et al.*, 1995), it has not been used in many prosecutions of illegal polluters. However, other forms of remote sensing have been used extensively for evidence and law enforcement purposes, such as aerial photography (Gillen, 1986) radar speed guns, video cameras, (R. v. Nikolovski, 1996) and forward-looking infrared systems (R. v. Tessling, 2004).

Aerial photography is one form of remote sensing that is often used to encourage pre-trial settlements and during court cases. Gillen (1986) discusses how maps and aerial photographs have been used extensively in the courtroom and provides recommendations on how they should be presented. Most maps are used as demonstrative evidence to provide a clear display of the crime scene to the courts. Polet *et al.* (1986) and Dams *et al.* (1986) presented the use of colour infrared aerial photographs to settle insurance claims made against companies that were involved in accidental release of chemicals into the environment.

The history of aerial photography within the legal system will be examined to provide a foundation in the discussion of SAR for legal use. Some of the parameters to be investigated include how it is presented in court and potential legal barriers, if any, in the validation process, the purpose or role of aerial photographs in the courtroom and the specific legal application areas. Most literature provides guidelines on the use of both maps and aerial photographs concurrently. However, only applications using aerial photographs and satellite imagery will be addressed in this research mainly due to the fact that both are forms of remote sensing.

2.1 Guidelines for use of Aerial Photography

Both vertical and high oblique photographs have been accepted evidence in courts. There are two main sources of legal guidelines for the introduction of aerial photographs as evidence. Most of the published guidelines for standard vertical photographs are found in the legal literature, and oblique photographs are documented by the Canadian federal government and other international organizations. The main purpose for using aerial photographs is to increase the visual comprehension of facts presented in court.

2.2 Legal Literature

The qualifications of the photographer and the quality of the equipment used can influence the admissibility of aerial photographs as evidence. Aerial photographs need to be authenticated as evidence in court to validate the identification of and responsibility for oils slicks on the ocean. Quinn (1979) provides a checklist for an expert witness to follow when using aerial photographs as evidence. This includes specific details on the photographs, photographer, plane and the weather and atmospheric conditions. The checklist also includes when and where the photographs were taken as well as the photographer's name, address and experience. Other details on the camera include type of film, how and where the film was processed, scale, custodian of the film and shutter speed, the pilot's name and the altitude of the plane. This comprehensive list is needed in order to authenticate aerial photographs as evidence in court.

Furthermore, the photographer must identify the subject (aerial photograph) and testify that it represents the geographical area that is the subject of the particular court case. Aerial photographs have also been admissible when a licensed engineer or registered surveyor has personal knowledge of the location and can state that the picture is a true representation of the area.

Aerial photographs are admissible in court when they are relevant to the dispute and are presented by an expert witness who will testify that they are a fair and accurate representation of the subject in question. The expert witness does not necessarily have to be the photographer; it can be anyone who has relevant experience in the field and a strong knowledge of the discipline. All material in the case should be collected using a fact sheet or notebook. It is suggested to have the witness rehearse precisely what is to be done in the courtroom demonstrations (Gillen, 1986). The following guidelines recommended by Gillen (1986) for using visual displays as supporting evidence in court include that the labeling must not be offensive; graphics should be enlarged (approximately 1 m) and be seen from a distance of 6 to 12 m; photographs should be mounted on foam board or similar material for easy handling in court; and scale should be easily visible by everyone in the courtroom, with a bar or graphic scale proven to be the best format.

To be presented in one court case, aerial photographs were scanned, input to a computer, mosaicked and printed onto a poster board for visual purposes. Data and methodology validation for Geographic Information System (GIS) evidence requires that each process and data source be well documented and the accuracy verified to stand up in court. Furthermore, the importance of quality control of any outgoing products must be performed (Curley, 2005). Hence, in the context of this research, the same requirements would be needed in the presentation of satellite imagery as evidence.

Two common topics discussed in the literature described above include 1) the need for aerial photography to be relevant to the particular court case and 2) the importance of an expert witness being able to explain the accuracy and processing steps used to create the final product presented in court. The importance of good graphics is also emphasized in presenting this evidence as a mechanism to increase visual comprehension of the facts presented in court. Guidelines on the most appropriate presentation style for aerial photograph exhibits are highlighted, such as enlarged samples on poster type board and the use of a scale bar (Gillen, 1986).

Finally, the actual presentation in court of the entire procedure has to be clearly and concisely outlined using standards and proper quality control measures defined by the particular remote sensing discipline. In the verification of SAR slick detection, aerial photographs are a piece of evidence that provides a visual representation of the oil slick's location and extent on the ocean at a particular date and time.

2.2.1 Aerial Surveillance Handbooks

Three aerial surveillance handbooks that provide guidelines and instructions on how to identify oil on the ocean's surface include the Canadian Coast Guard (now Transport Canada) *Standard Operating Procedures for Pollution Prevention Officers During Aerial Surveillance Missions* (Transport Canada, 2007), the *Bonn Agreement Aerial Surveillance Handbook* (Bonn Agreement, 2004) and the *International Tanker Owners Pollution Federation* (ITOPF) *Technical Information Paper: Aerial Observation of Oil* (ITOPF, 2001). The Transport Canada *Standard Operating Procedures* (SOPs) document has adapted some of the *Bonn Agreement* guidelines and provides guidance to personnel conducting pollution patrols under the National Aerial Surveillance Program.

The *Bonn Agreement* is a collaborative effort of northern European countries, including Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden, and the United Kingdom, to help combat oil pollution in the North Sea. The agreement was signed on September 13, 1983 and produced many manuals on the identification of oil at sea and legal prosecutions, including the *Bonn Agreement Aerial Surveillance Handbook.* The coding system in this handbook was developed in accordance with scientific literature and previously published papers, supported by laboratory experiments, outdoor experiments and controlled sea trials (Bonn Agreement, 2004).

The *Aerial Observation of Oil* handbook (ITOPF, 2001) is based on operational experience from oil spill response and the use of aerial surveillance. The ITOPF is an international organization that has responded to more than 430 ship-source oil spills, in over 80 countries, to provide advice on clean-up measures, environmental and economic impacts and compensation. The handbook provides advice and guidance on conducting aerial reconnaissance at sea. All three handbooks provide similar guidelines for the visual identification of oil slicks on the ocean's surface during aerial surveillance missions.

2.2.2 Canadian Government Oil Spill Surveillance Program

Oblique aerial photography, in analogue or hard copy format, has been used as evidence by the National Aerial Surveillance Program (NASP) for illegal oil slick court cases. Visual aerial surveillance, in conjunction with testimonials from crews, has resulted in numerous prosecutions, with the highest fine of $170,000 (Armstrong, 2007). Until 2007, all of the pollution incidents prosecuted in Canada were based on witness testimony and supporting photographic evidence, and none have used oil samples. From the NASP's perspective, the main legal constraint is the admissibility of earth observation data, such as satellite imagery, which has only been used to guide ground assessments, rather than forming a primary basis for evidence (Armstrong, 2007). However, there is no further documentation on the specific legal constraints that might exist.

Oblique photographs captured during aerial surveillance missions meet the legal requirements, as they have already been accepted as evidence in court. Legal guidelines exist for the use of oblique aerial photographs as evidence in the court of law. Legal guidelines for using these aerial photographs as evidence in Canada are provided in the Transport Canada *Standard Operating Procedures* (SOPs) *for Pollution Prevention Officers During Aerial Surveillance Missions.* The following section describes the guidelines, which are also relevant to the authentication of SAR imagery (Transport Canada, 2007).

Pollution Prevention Officers (PPOs) have a detailed procedure for gathering evidence of illegal oil discharges. While on surveillance flights, the PPO has to make detailed notes of an event. As much information as possible should be collected about the incident and include: a chronological summary of the incident from the time the aircraft first arrived on the scene to the completion of the investigation; photo and video times; documentation of when the oil stopped trailing the ship; visible discharges, activity on the deck, stains on the hull and observation records of the oil including slick dimensions, coverage, and oil categories; weather conditions, wind and sea state; pollution message logging data and anything else deemed important (Transport Canada, 2007).

The PPO should carefully observe the ship, ahead of and abeam, to determine if oil is present and all vessels in the area should be inspected and documented for possible presence of oil. The name, time, position, course and speed information on the other vessels must be reported. Physical shape characteristics of the oil slick as a whole, consistency, windrows, spots, streaks, and dispersing should also be documented (Transport Canada, 2007).

All evidence gathered during a surveillance mission must be documented and protected to maintain continuity, which is essential for authentication. An incident file is created for each potential illegal oil slick case and may result in enforcement action. Any photocopies of the documents should be dated and initialed by the person making the copies. The person who took the photographs should initial all copies of the photographs. The guidelines for taking photographs include flying to a high altitude (450 m – 600 m) and allow a single photograph field-of-view to capture the vessel, pollution and forward track of the vessel. If at all possible, photographs should not be taken looking into the sun for the contrasts to be maximized. When a digital camera is used, no photos should be erased even if they did not come out clear. Viewing angle is critical when detecting oil, with the optimum angle being 90° to the horizontal. When the viewing angle changes from 90°, a vertical view, to 55° from the horizontal, detectability of the eye and camera decreases over 50% for most oil types. Detectability can be degraded from 70% to nil, when the viewing angle from the horizontal reaches 35°. Wind streaks, thermal differences in the ocean's surface temperature and cloud shadows can create variations in texture, tone and pattern that can be confused with the presence of oil. When viewed from the vertical, with the sun at the observer's back, these features disappear, but oil is still visible (Transport Canada, 2007).

Digital photographs should be downloaded to a computer and copied to a disc, which is dated, labeled, initialed and kept in the incident file folder. Digital photos of an incident sent electronically should include a warning that these may be used in enforcement action and should not be distributed to people not involved in the investigation. The items to be included in the incident file are: dated lists of all reports, photos and digital images that are distributed to persons involved; copies of all correspondence, reports, electronic missions reports and maps relating to the incident; copies of all photos and original negatives, digital images and discs, original remote sensing data, original video and audio tapes; original Global Positioning System (GPS) log; a copy of the aircraft journey log page for date of incident and copies of all crew notes relating to the incident. All copies of the photographs and flight reports are kept in three separate locations, which include the local Canadian Coast Guard (CCG) office, the CCG head office in Ottawa and Provincial Airlines Limited in St. John's. Flight reports are generated by the computer system on board the surveillance aircraft (Canada Coast Guard, 2002a).

If an oil slick is verified during a surveillance mission, three copies of all the photographs, compact discs (CDs), videos and violation reports are created, and two copies of the flight report are made. When used in court, the PPO needs to agree with the oil slick calculations, such as length, width and volume the onboard computer generated (Transport Canada, 2007). The original photographs and any video recordings are held in a secure locked cabinet at Provincial Airlines Limited, Offshore Surveillance Branch offices (Personal Communication, Gerry Mallard, 2007).

Transport Canada has learned many lessons from previous unsuccessful cases (Armstrong, 2007). Some of the issues that influenced cases to fail in the past included inconsistencies with electronic reports; copies printed on different dates with different overlay data depicted; incorrect latitude manually put into the camera data annotation system; no overview photos showing the oil slick extents, including a photo showing no oil in front of the ship; and a two degree latitude or longitude difference between the ship track and the oil slick represented a reasonable doubt.

The authentication of vertical and oblique photographs require similar information, which include specific details about the aerial photos and aircraft, custodian of the photographs, and weather conditions such as wind conditions and sea state. The chronological summary of all events needs to be documented in order to show a chain of custody, and all original copies of photos and documents have to be shown in court, with no inconsistencies or discrepancies found in the data that can hinder the admissibility of the data as evidence in court.

2.3 Court Cases

The Canadian Legal Information Institute (CanLII), Supreme Court of Canada and the World Legal Information Institute (WorldLII) websites were reviewed to determine the extent to which aerial photographs have been used as legal evidence (CanLII, 2007; Supreme Court of Canada, 2007 and WorldLII, 2007).

The CanLII on-line database revealed over 350 court cases using aerial photographs as evidence. The majority of the cases contained themes of land boundary and property ownership disputes and wildlife hunting boundary disputes. One key use of aerial photographs was the detection of changes in land features and man-made structures, such as buildings and roads by using photos from several dates (i.e. annually). The Supreme Court of Canada's on-line database contained two cases using aerial photographs; one case dealing with a land use issue and one dealing with the illegal cultivation of drugs. The WorldLII database yielded over 1000 cases using aerial photographs. The main thematic areas are automobile accidents and land use planning (CanLII, 2007; Supreme Court of Canada, 2007 and WorldLII, 2007).

The information provided in these databases showed that aerial photographs were used as evidence to identify land features and for verification purposes in civil and criminal cases. In addition, both the originals and photocopies of aerial photographs were used in court. The only known satellite imagery case used optical imagery in the identification of a pollution discharge. Optical imagery is comparable to panchromatic aerial photography as they both use the visible portion of the electromagnetic spectrum (i.e. those wavelengths to which the human eye is sensitive).

2.4 Satellite Imagery

There is a general acceptance of aerial photography for legal use, while a number of cases worldwide have used satellite imagery (Table 2-1). Ten out of the eleven court cases depicted in this table used optical satellite imagery, and one case used satellite SAR. The following paragraphs provide a detailed description of the individual court cases.

Latin *et al.* (1976) discuss one of the first prominent cases to use satellite imagery in the United States (U.S.), the State v. Inland Steel Company, 1976. This case dealt with a facility in Indiana that discharged contaminants into Lake Michigan. The State of Illinois wanted to prove that the health of citizens was endangered by this discharge. Therefore, the state began their investigation by collecting water samples from the plume to match with the facility. Thermal infrared aerial photographs showed the direction of the plume and the length was measured from a Skylab colour image. Both pieces of evidence provided the basis for a court decision in favour of the State.

Ginzky (2001) describes four other cases in the United States. The first one was the United States v. Reserve Mining Company, 1974, which dealt with tailing discharges from a mining facility into Lake Superior. In this case, both the company and the EPA submitted satellite images to help determine whether the discharge in the lake came from

Table 2-1 Satellite imagery accepted as evidence

Court Case, Year	Reference	Location of Court Case	Application			Trial	Platform	Data format	Expert Witness		Auxiliary Data
			Pollution	Boundary	Criminal				Yes	Unspecified	
State v. Inland Steel Company, 1976	Latin *et al.*, 1976	U.S.	•			Y	K	U	•		AS
U.S. v. Reserve Mining Company, 1974	Ginzky, 2001	U.S.	•			Y	LK	U	•		A
Chevron U.S.A Inc. v. U.S., 1981	Ginzky, 2001	U.S.		•		Y	U	U		•	U
Gasser v. U.S., 1988	Ginzky, 2001	U.S.	•			Y	U	U		•	U
ANR Production v. M/V Mekhanik, 1989	Ginzky, 2001	U.S.	•			Y	U	U		•	U
I&M Rail Link v. Northstar Navigation, 1998	Markowitz, 2002	U.S.		•		Y	U	U		•	U
Botswana v. Namibia, 1996	Markowitz, 2002	ICJ		•		Y	L	U	•		U
Qatar v. Bahrain, 2001	Paulson, 2001	ICJ		•		Y	U	V		•	AG
Visual Forensics, 1998	Fadaie *et al.*, 2001	Italy			•	Y	U	D	•		A
Maritime and Port Authority, 1996	Fadaie *et al.*, 2001	Singapore	•			N	E	D	•		GS
Ship Dumping, 2002	Maritime Safety Authority	Australia	•			Y	P	DV	•		AG

Abbreviations: Location: ICJ: International Court of Justice; U.S.: United States; Trial: Y: Yes; N: No; Platform: E: ERS; L: Landsat: K: Skylab; P: SPOT; Data format: D: Digital; V: Video; U: Unspecified; Auxiliary data: A: Airphotos, G: Ground photos, S: Field sampling.

the mining facility or from a natural source. The images proved that the plumes were of a natural origin. In the second case, Chevron U.S.A. Inc. v. United States, 1981 the EPA used scale-enlarged satellite image displays to delineate the exact acreage of an area they wanted to declare as a Wilderness Area. In Gasser v. United States, 1988 satellite images helped to determine whether a plaintiff was entitled to compensation by the government because flooding had damaged their property. In the last case, ANR Production v. M/V Mekhanik, 1989 satellite images were used for the property damage claim when a passing ship damaged an oil platform. The satellite images proved that the visibility conditions were good on the day the accident happened. In all of these four cases satellite imagery was admitted as evidence, without questioning its admissibility.

Markowitz (2002) discusses two additional satellite cases, I&M Rail Link v. Northstar Navigation, 1998 and an International Court of Justice (ICJ) case between the African countries of Botswana and Namibia. In the I&M Rail case, satellite images were used to determine whether a barge accident occurred in Illinois or Iowa. In the Botswana v. Namibia, 1996 case, a dispute over national boundaries was brought before the United Nations. The case involved the use of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) taken in 1975 and aerial photographs taken between 1925 and 1985 that helped determine the width and depth of a main channel in the area. Markowitz (2002) suggests that courts will continue to be reluctant to consider satellite images as evidence until scientists and attorneys begin to work together to develop protocols for the general acceptance of this technology. A serious dialogue needs to occur between the scientific and legal communities, in an effort to create a set of principles or rules of evidence that govern remote sensing data.

Paulsson (2001) discusses the case of Qatar v. Bahrain, 2001 that effectively used satellite data, photography, infrared scanning, hydrographic studies, expert reports and historical charts to help settle a boundary dispute. Fadaie *et al.* (2001) discusses two other cases using satellite imagery. The first case involved a company called Visual Forensics. Visual Forensics develops computer models for criminal cases that have proven to be effective in court. For example, in Italy, Visual Forensics used a digital model to help acquit a pilot of murder, who was alleged to have been flying too low, resulting in the deaths of 20 people on a sky lift. The model created a representation of what the pilot saw as he was flying the aircraft. This emerging technique, forensic visualization, is the realistic reconstruction of events using geospatial information as evidence in criminal cases. These digital simulations include the use of satellite images, digital aerial photographs, and auxiliary data. The second case used an ERS (European Remote Sensing satellite) SAR image to locate a ship which was leaking oil off the coast of Singapore. The Singapore Maritime and Port Authority used an ERS image and ground photographs taken from the shoreline of the ship leaking oil, along with other evidence, to build a strong case against the ship owner of the MV Song San. The evidence in this case was presented to a Magistrate and did not go to trial. The ship's owner pled guilty to the oil pollution and was fined approximately C$100,000 and the ship's captain received prison time. This was the only marine oil pollution case found to have used satellite SAR in a prosecution (Fadaie *et al.*, 2001).

In 2002, the Australian Maritime Safety Authority used an optical SPOT-4 satellite image to prosecute a ship illegally dumping oil off the Great Barrier Reef. The chain of custody of the incident was documented with the weather conditions and the geographic location of the slicks matching the SPOT-4 image, which was verified with aerial surveillance and video. A hard copy of the satellite image spatially aligned with other map data, such as the coastline and reefs were used as evidence in court (Personal Communication, Australian Maritime Safety Authority, 2005).

The main applications areas for satellite imagery in these legal cases were boundary disputes and pollution cases. Furthermore, nearly half of the cases that employed optical satellite imagery also used aerial or ground photographs as supporting evidence. The cases revealed that satellite imagery along with photographs increases the visual comprehension of facts in a court case. The majority of the court cases used an expert witness and required documentation of all corresponding data used with the satellite imagery. All cases showed that satellite imagery was useful at revealing the true facts of each case leading to a successful conviction. The majority of cases (more than half) were from the United States, with other cases from Italy, Singapore, Australia and the International Court of Justice.

In many law enforcement cases where satellite remote sensing has been used, most lawyers feel a stronger case can be built on evidence collected on the ground (Davies *et al.*, 1999). In addition, they choose to rely on airborne rather than satellite data, mainly due to the fact that aerial photography presented the opportunity to collect more detailed information. Satellite imagery has been used mainly to target on-the-ground assessment rather than forming a primary basis for evidence. Satellite imagery has also been used for many boundary disputes and environmental monitoring by a number of countries, such as Brazil, to monitor the Amazon Region, Indonesia and Singapore. In addition, citizen groups from different countries use satellite remote sensing to identify and prosecute those violating environmental laws and as an advocacy tool (Davies *et al.*, 1999).

2.5 Other Remote Sensing Devices

Law enforcement officials have used a variety of remote sensing devices in routine enforcement, monitoring and evidence in court. These devices include radar and laser based speed guns, video cameras, and Forward Looking InfraRed systems (FLIR).

Radar uses micro waves to detect the presence of objects and to determine their distance and sometimes angular position. The process involves short pulses of energy and the recording of the signal or strength of "echoes" received from the object within the system's field of view. This process is designed to achieve higher spatial resolution imagery. Radar systems are either imaging or non-imaging, and they can be mounted on ships, aircraft or spacecraft such as RADARSAT-1 SAR, which like ERS SAR, is an imaging radar. Non-imaging radar systems, such as speed guns are used by enforcement officials to determine the velocity of a target of interest (Lillesand and Kiefer, 2000). All radars operate in the microwave portion of the electromagnetic spectrum. Radar speed guns were first introduced as X-band (7 - 12 GHz frequency, 2.4 - 3.75 cm wavelength), then K-band (18 - 26.5 GHz, 1.1 - 1.67 cm) and Ka-band (26.5 - 40, GHz 0.75 - 1.1 cm). RADARSAT-1 SAR and ERS are C-band (5.3 GHz and 5.6 cm). However, there are other radar satellites with finer resolution, such as TerraSAR-X, which operate in the same microwave bands as radar speed guns. Police also use laser radar guns or LIDAR, which operate in the infrared spectrum band. Speed guns do not produce images; they are active single point detection systems (Lillesand and Kiefer, 2000).

Video cameras are frequently used in most commercial businesses for surveillance activities. Videotape has been shown to be an effective visual tool, mainly due to the fact that people can easily relate it to a television set (Gillen, 1986). However, when this new technology was first introduced as evidence, it faced legal challenges related to admissibility and authentication (R. v. Nikolovski, 1996). These challenges included the fact that a person did not operate the video camera, and therefore the data could not be authenticated (Personal Communication, Robert Currie, 2005). This further affected admissibility until this one court case used this technology as evidence and set a precedent in 1996.

FLIR systems have been used to locate illegal drug growing operations and have created enormous controversy in the courtroom (Smith, 1996). Police have operated this thermal infrared (8 -12 μm) passive heat-detecting device to locate buildings giving off a higher heat, which may indicate illegal growing of marijuana. The device has led to a high false alarm rate, consequently too many search warrants have been issued. However, the technology is still used on a regular basis in Canada (Smith, 1996).

A variety of remote sensing devices, similar to SAR imagery has been used in routine enforcement activities and as evidence in court. However, when these devices were initially introduced, many faced legal challenges regarding admissibility until a precedent was established from a first successful court case.

3 LIMITATIONS RELATED TO THE USE OF REMOTE SENSING IN COURT

The main limitations related to the use of remote sensing data in the court process are the admissibility and authentication of remote sensing data. The admissibility and authentication of satellite imagery as evidence in the court process are addressed in this research.

3.1 Admissibility

The most prevalent issue with respect to the use of SAR as evidence in a prosecution is its admissibility, which is based on judicial and technical standards (Marks 1989). Evidence is defined as information that determines a fact in a legal dispute (Paciocco and Stuesser, 1999). Admissibility is when evidence is permitted to be presented or worthy of being accepted in court. A judge determines whether the particular information can be used, and it must be relevant to the court case in order for it to be accepted. The two other factors that contribute to the admissibility of evidence are the expert witness qualifications and the evidence reliability. Judges in Canada are governed by the *Canada Evidence Act (1996)*, which regulates the rules of evidence and type of evidence that can be submitted. The implication of this Act is that it may limit the admission of new forms of evidence, such as satellite imagery due to the resistance to change, as some judges may be reluctant to accept new types of evidence.

Once the evidence is deemed relevant, the next factor affecting the admissibility of evidence is the expert witness's qualifications, as defined by the particular legal system, to explain the type of evidence presented in court. Both the prosecution and defense lawyers can present expert witnesses and present to the court the extent of their accomplishments, experience and professional reputation. Furthermore, a description of the expert witness's focus within a particular discipline and the manner of presenting the evidence must also be considered (Sopinka *et al.*, 2004). The role of an expert witness is to establish the reliability of scientific theories and techniques of the sensors, to document that the particular device presented is consistent with these scientific theories, to identify the submission as the original output produced and to interpret the information in a manner which is meaningful to the trier of fact (Latin *et al.*, 1976).

Remote sensing evidence must be explained in everyday terms for a non-expert and the witness should be prepared to explain in an effective manner the particular discipline of remote sensing and how it is relevant to the particular court case. The science of remote sensing, including its terminology, can be difficult to explain in layperson's terms; hence, an expert witness should have well-prepared documentation before appearing on the witness stand.

In the past, the use of satellite imagery has raised the concern of U.S. constitutional rights violation, which can also affect admissibility; however, this has not shown to be a large problem. Geer (1991) discusses a case of Dow Chemical Co. v. United States, 1986, in which the Supreme Court found that satellite imagery did not violate the Fourth Amendment to the U.S. Constitution, which protects people, not places or open areas. Geer (1991) suggests that some of the key points to consider when determining whether information derived from satellite imagery can potentially violate constitutional rights include whether it is available to the general public or whether it penetrates the external structure of buildings. There were no cases documented in Canada on the use of satellite imagery potentially violating constitutional rights; however, there was a case surrounding the use of FLIR. In a Supreme Court of Canada case, R. v. Tessling, 2004, the Royal Canadian Mounted Police used FLIR technology to initially locate the illegal growing of marijuana in an individual's home. In a lower court, the accused was first acquitted based on the fact that the use of FLIR was a violation of his constitutional right to be free from unreasonable search and seizure, Section Eight of the Canadian Charter of Rights and Freedoms (Electronic Frontier Canada, 1982). However, when the case went to the Supreme Court, the person was convicted, and the FLIR device was not found to have violated privacy rights.

The legal system uses many factors to determine the reliability of scientific evidence including its acceptance in the scientific community or within the relevant professional disciplines, assignment to a scientific discipline, the non-legal uses of a technique, subjective interpretation and uncontrolled variables (Latin *et al.*, 1976). A principal component of admissibility is that the scientific technique must have passed from the experimental to the demonstrative or operational stage (Marks, 1989). Forensic devices, such as lie detectors, radar guns, sound and video recordings have been used previously to uncover the truth. It seems logical that satellite imagery should follow a similar trend to establish facts (Marks, 1989).

The established standard for the admission of scientific evidence in the United States was set out in the 1923 case of Frye v. United States. Frye established a "general acceptance in the scientific community" as a test of the admissibility. However, according to Ginzky (2001), the scientific community has abandoned the Frye standard and the Daubert v. Merrel Dow Pharmaceuticals, 1993 case is now the accepted standard, to determine if a technique is reliable. The Daubert standard is the most recent U.S. Supreme Court decision outlining criteria for admitting scientific evidence. In Canada, the Supreme Court of Canada case R. v. Mohan, 1994 is the equivalent test used to determine the admissibility of scientific evidence. In the case of R. v. Mohan, an expert witness advancing a novel scientific theory or technique was subjected to special scrutiny to determine whether it met a basic threshold of reliability and whether it was essential in order to come to a satisfactory conclusion without the assistance of this expert. The implication of not needing an expert witness is that once their reliability is established, radar images will be able to be presented in court without a witness. Therefore, evidence can be dismissed solely on the account of not addressing threshold levels of accuracy.

In establishing the reliability of evidence, the courts consider the degree to which the scientific evidence can be categorized into a single or number of well-recognized scientific disciplines. The technology must have been proven and the underlying scientific principles must have received substantial validation within the applicable discipline, and acceptance by the law enforcement officials, but the general community at large. Other criteria needed to establish the reliability of evidence include the degree of accuracy and the repeatability of the methodology. Accuracy is the ability to measure a method within a certain level of error, while repeatability is the ability to produce consistent results within this defined level of error. Uncontrolled variables include factors that are sometimes unpredictable and generally external to the technology being used. In the context of remote sensing, uncontrolled variables may include prevailing environmental conditions present at the time the image is being recorded (Latin *et al.*, 1976).

Marks (1989) states that the lack of established remote sensing standards for the technology, the lack of lawyers with adequate education in the field of remote sensing, underdeveloped data management and distribution systems and limited data availability are some of the reasons why remote sensing is not being used more by the legal community. The lack of technical standards may have weakened the recognition of remote sensing data as a potential form of evidence and may have led to the miscommunication about the standards and technology to the legal community. There are general rules, such as those set out in the Daubert and Mohan cases discussed earlier (Markowitz, 2002; Sopinka, *et. al.*, 2004); however, there is no set standard for satellite remote sensing. Although the Canada Evidence Act and Case Law sets out the basic principles to be applied, the final decision on the use of satellite imagery is a matter for the individual judge's ruling on a particular case.

3.2 Authentication

Once evidence is found to be relevant and is admitted in court, it must also be authenticated, establishing the identity of the submission. For graphic representations, including photographs and remote sensing output, the authentication can be addressed in two main ways: (1) whether the image actually depicts what it intends to and (2) whether the image submitted is legally equivalent to what was initially obtained (Marks, 1989). The legal system usually requires the identity of a submission to be proven by external facts and testimony rather than by inspecting the submission's contents (Marks, 1989). The first step in the authentication process is the testimony of an expert witness who observed the object used, the document written, or the events which occurred. A complete chain of custody for the evidence must be documented. The evidence should be directly traceable from the moment it was collected or assumed legal significance to the time of submission. Each custodian should verify that the evidence was preserved in an unchanged format during his or her possession. The more remote sensing data are processed or enhanced from its "raw" primary form, the more difficult it is to prove its contents (Marks, 1989). Image enhancement as defined by Lillesand and Kiefer (2000) is the process used to improve the visual interpretation of an image by increasing the apparent distinction among features. From a remote sensing perspective and in contrast to Marks (1989) the image processing steps can easily be traced from the beginning of the analysis to the final product generation; therefore, it does not make it difficult to prove what is contained within the image.

Latin *et al* (1976) discuss how the most unusual category of remote sensing output from a legal perspective is that of "enhanced images." Computer processing techniques used by remote sensing analysts, such as density slicing, help to locate features that would not normally be identified without applying this technique. According to Latin *et al* (1976), the word "enhance" actually implies that the image is altered from its original state, which is a typical required format for evidence. Remote sensing data need to comply with the formal rules of evidence; however, data collection methods vary widely with respect to reliability and procedures (Latin *et al,* 1976). The submission of remote sensing data as evidence must remain parallel with other types of scientific evidence. In addition, consistent methods for establishing reliability and documenting data collection must be developed.

Under statute or a law enacted by the legislative branch of a government, a variety of public and judicial records are admissible without proof of genuineness. In the U.S., the use of documents in a trial are also subject to the "Best Evidence Rule," which requires that the original document be submitted when there is a need to prove its contents (Paciocco and Stuesser, 1999). Satellite remote sensing can be admitted into court as evidence either as demonstrative evidence under the U.S. Federal Rule of Evidence 1006 or as scientific evidence under Federal Rule of Evidence 702-703. The U.S. Federal Rule of Evidence 901 (a) requires that any document admitted into evidence is authentic (Krowse *et al.*, 2000). For example, a map published by the U.S. government is self-authenticated under the government - Rule 902(5) (Markowitz, 2002). Remote sensing images such as Landsat may be authenticated as public records under the U.S. Federal Rule of Evidence 901 and 902 due to the fact they are collected by government departments or agencies. Since computers are heavily used in their production, digital maps face reliability challenges as computer evidence. A similar evidence rule in Canada that self-authenticates maps or satellite imagery was not found during this research. However, in Canada and the U.S., similar technological processes and protocols are used in the making of satellite images, where identical legal principles should apply.

The process of extracting information from digital spatial data must be documented. The geomatics community has put considerable effort into establishing standards for the processing and easy exchange of geospatial data. The term "standard" is defined by the Standards Council of Canada as an accepted technical requirement and terminologies for products and services, or an agreed upon set of criteria or rules by which things are measured (Standards Council of Canada, 2000). A standard is a set of procedures that are accepted practice within a particular discipline. Some of the standard bodies include the U.S. Federal Geographic Committee, the Open Geospatial Consortium and the International Organization for Standardization (ISO) Technical Committee 211 (TC 211). These standard bodies have addressed specific remote sensing parameters such as metadata, swath, orthoimagery, image co-ordinate transformations and conversions of data formats. Metadata is the information that describes the data, such as resolution, co-ordinate system and file type. Lineage metadata standards have mainly concentrated on the exchange and sharing of datasets (Liping, 2003). Metadata standards are the most relevant to the legal documentation of authentication, and it is the process which the remote sensing community uses to describe the data and their quality. The standards for the other parameters such as swath, orthoimagery, image co-ordinate transformations and conversions of data formats facilitate the transfer, sharing and communication of data within the remote sensing community.

Wong and Wu (1996) describe metadata as detailing the quality and accuracy of the information contained in the data, such as lineage, positional accuracy, completeness, attribute accuracy, and logical consistency. These can be used to address the authentication of satellite imagery, which is needed for its use in court cases. Metadata allow the producer of the data to describe a dataset so that other potential users can fully understand the assumptions and limitations of the data and assess if the dataset is appropriate for other applications. The concept of metadata promotes the repeated use of the data by other potential end users. Hence, the need to properly document the details of the data is essential (Tschangho, 1999). According to Duncan (2003), metadata plays a strong role in the reliability of spatial data. Considering the level of documentation described in the metadata, this level of detail can assist in establishing the authentication of satellite imagery.

A theme in the literature (Gillen, 1986; Marks, 1989) is the importance of good graphics for scientific data when presented as evidence. It is essential for the entire processing sequence to be documented. A graphic approach needs to be established when satellite imagery is introduced in court. For example, a flowchart detailing specific events of how satellite imagery was used in an enforcement activity such as SAR oil slick detection is required.

4 METHODOLOGY

To address all three objectives for this research, the following methodological steps will be performed (Figure 4-1). The first objective will uncover the challenges of using remote sensing as evidence in the prosecution of illegal oil discharges. The visual interpretation process of oblique aerial photographs and SAR imagery for oil slick detection will be reviewed to address authentication. Image interpretation involves three main steps, which include the identification of the objects, the measurement of objects, and the use of this information to help in the solution of a particular problem (Reeves *et al.*, 1975). A comparative analysis between the image interpretation steps of using oblique aerial photographs and SAR imagery will be carried out and similarities between the two will be used to determine whether or not an argument can be built for the use of

SAR imagery as evidence. To address the second objective of preparing the technological parameters for the validation of SAR images to be used as evidence, a review of the Integrated Satellite Tracking of Oil Polluters (I-STOP) slick detection process (Turpin, 2003) for legal use will be performed. A RADARSAT-1 image from the I-STOP program will be processed by using existing knowledge gained from the legal use of aerial photographs, remote sensing standards and other documented legal guidelines. The same steps in the aerial photograph interpretation process put in the context of the legal requirements of admissibility and authentication will be reviewed when extracting visual information from a RADARSAT-1 image. This procedure will help to illustrate whether or not there is a potential for SAR imagery to be used as evidence and to suggest a possible template for an expert witness to use. This method concentrates on image interpretation of analogue oblique aerial photographs and digital SAR imagery; however, the same method can be applied to digital oblique aerial photographs rendered in analogue format by a computer monitor or hard copy printout.

4.1 Admissibility

As discussed in Section 3.1, admissibility is obtained when evidence is accepted in court. In order to have aerial photography or SAR images admitted as evidence, the competency of the expert witness must be demonstrated and the reliability of the data shown. An expert witness who has the relevant experience must explain the method and technology used. Court cases and legal literature are reviewed to determine the types and level of qualifications of an expert witness for aerial photography evidence. The reliability is determined by the accuracy and repeatability of the method. This is investigated by reviewing various journal articles and documented visual interpretation techniques.

4.2 Authentication

Evidence is authenticated by the court when it is proven to actually depict what it is supposed to and demonstrated to be legally equivalent to what was initially obtained. The authentication of aerial photographs and SAR imagery as evidence for oil slick detection is examined by showing the processing steps and by illustrating the standard practices that are used in this process. Authentication can be addressed in the context of satellite remote sensing imagery by documenting the metadata and legal guidelines in the creation of a product. The processing steps ensure the use of a proper chain of custody, which is required by the legal community. In the identification of features on the ocean surface using an aerial photo and SAR imagery, several visual interpretation steps are used. Traditionally, analog visual interpretation uses parameters such as shape, size, tone, texture, pattern, site and association.

Shape refers to the general formation of individual objects in a remote sensing context, where a two-dimensional shape refers to the outline or form of an object. Size is a measurement of the dimension of an object or area, which can be determined by the scale of the photograph and the spatial resolution of the image. Tone is the relative brightness of objects or areas in an image. Colour is the amount of red, green or blue in an image.

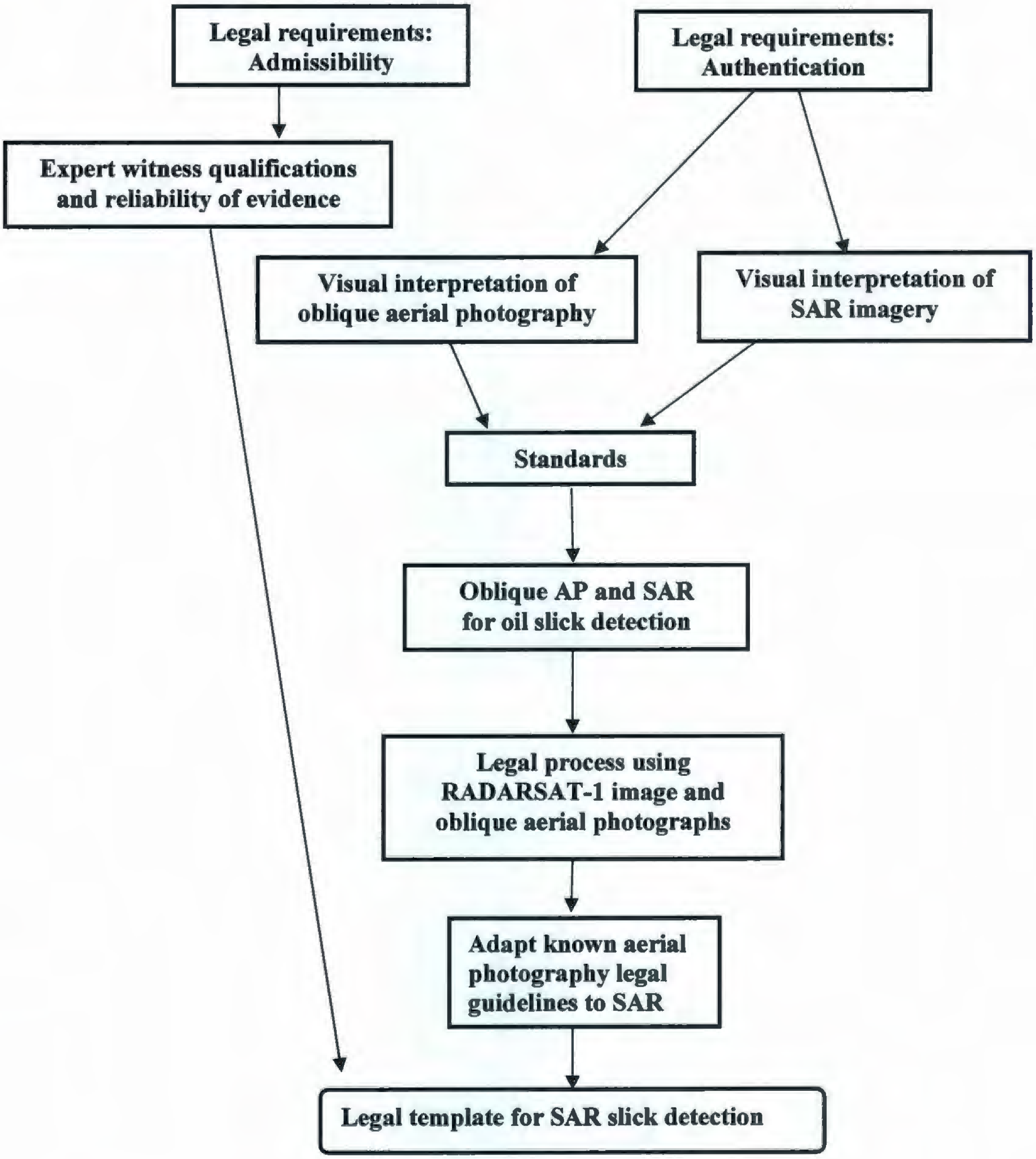


Figure 4-1 Methodology for the use of SAR imagery in legal cases

Texture can be defined as the spatial frequency of tonal or colour changes, which may be caused by the repetition of groups of objects that are often too small to be visually identified as single features (Reeves *et al.*, 1975). The texture of a feature is described by the terms smooth (low spatial frequency) or coarse (high spatial frequency). Pattern is defined as the spatial arrangement of objects and similar forms in the landscape, which can be arranged as continuous, random or systematic. Site is the unique physical or socioeconomic characteristics of a feature, and association refers to the occurrence of certain features in relationship to others. Association is the when objects usually occur in a geographic area with other features (Jensen, 2007). The visual interpretation procedure of identifying oil slicks in oblique aerial photographs and SAR imagery, along with the associated metadata practices, are reviewed in Section 6.1.1 to determine the accepted procedures within the discipline.

4.3 Analysis of Aerial Photography and SAR imagery

By analyzing the information gathered using aerial photography and SAR technologies and interpretation methods, the synergies are highlighted. The image interpretation process in oil slick detection using oblique aerial photographs and SAR imagery are also analyzed here from a legal perspective. Furthermore, the guidelines for the use of aerial photographs in court cases, outlined in the legal literature review Section 2.1, are applied to SAR oil slick detection. Similar characteristics such as metadata and chain of custody guidelines for oblique aerial photos are assessed for their applicability to the use of SAR in legal cases.

4.4 Preparing SAR for Legal Use

In this thesis, the image interpretation steps followed during the I-STOP SAR slick detection program are reviewed for legal use. In an attempt to create a SAR oil slick detection product that can be considered as evidence, a radar image from the I-STOP program is processed. An image captured on September 08, 2002 was selected for this analysis because it contained a verified oil slick by the I-STOP team and led to a thorough investigation of an illegal oil discharge (Turpin, 2003).

The following image processing and interpretation steps will be applied in this analysis: pre-processing, image interpretation, validation and the creation of the final legal product. This review will result in methodological steps that can be summarized in a written report to accompany the analysis or a set of procedures to follow in court. Upon completion, this review will help prepare the authentication and validation of SAR slick detection for legal use as evidence.

The oblique aerial photographs from I-STOP were visually interpreted and supported the verification of the oil slick. The analysis will integrate auxiliary information, such as an oil observer's description on board the aircraft, wind data and other government documents from the September 08, 2002 incident. An eye witness account of the presence of an oil slick as seen by an oil observer or pilot of a plane is a piece of evidence that can be used in conjunction with the SAR image.

5 ADMISSIBILITY OF EVIDENCE

The admissibility of aerial photography and SAR for legal use as evidence is outlined by addressing the required qualifications of an expert witness and reliability for oil slick detection.

5.1 Expert Witness Qualifications

In order to address the admissibility of evidence, a qualified expert witness is needed to explain the type of evidence presented in court. It is difficult to determine who should be an expert witness for oil spill court cases. In Canada, the PPO who performed the visual identification of the oil slicks and actually took the photographs is expected to be an expert witness. A PPO or another person on board the surveillance aircraft, as an expert witness, has to establish their expertise, accomplishments, and recognition by their peers. Furthermore, their focus within a particular discipline and the manner of presenting evidence are other factors for consideration.

As with aerial photographs, the remote sensing image analyst who interprets the SAR image can act as a witness. This person should be ready to explain to the court all of the interpretation steps that were performed on the SAR image. In addition, this person should be able to verify that the satellite image was not tampered with, that the original image can be obtained from the SAR archive, if needed, and that the same oil spill product can be reproduced.

5.2 Reliability

As addressed earlier, the legal system stresses the need for scientific evidence to be accepted within the relevant professional disciplines. It is important that a scientific method has been proven and that the underlying principles have received substantial acceptance. The reliability of SAR slick detection is shown through the repeatability to produce the same results within a defined level of error and the validation of the technique.

Remote sensing scientists are trained in the scientific method, which involves a way of thinking about problems and attempting to solve them (Jensen, 2005). The scientific method includes inductive and deductive reasoning and a technological approach, which as documented by Curran (1987), is quite distinct from science and has its own philosophy and principles. The history of the scientific method within the context of aerial photograph and SAR slick detection is traced to illustrate the legal requirement of repeatability, and how the methods have been passed from the experimental to the operational phase.

Inductive reasoning is used when attempting to solve a new problem, with minimum prior knowledge on the particular subject (Jensen, 2005). Literature on the detection of oil slicks on the ocean dates back to the 1950s, when the first testing was performed on the visual properties of oil including its visual surface reflectance in an ocean environment (Cox and Munk, 1954). The next staged experiments for SAR slick detection were carried out to coincide with the launch of the first SAR satellite, ERS-1, which was called the Dedicated Oil Spill Experiment (Bern *et al.*, 1993). These were the first experimental attempts to detect oil slicks on the ocean.

Deductive reasoning is the process of problem solving or reaching a conclusion based on previous knowledge or experience of a theory that has been already proven. An example of deductive reasoning is the process of image interpretation. Features that are recognized on the image and identified directly lead to the identification of other features (Reeves *et al.*, 1975). Volckaert *et al.* (2000) analyzed oil slicks from aerial surveillance missions in the North Sea from 1991 to 1995 to determine the extent of oil pollution. Statistics were performed on all slicks to determine if any trends existed in the data, such as the size, area and volume of the oil slicks. Prior knowledge of oil slick detection was used in this analysis to help identity the slicks.

Technological approach is having *a priori* knowledge of whether to use certain technologies for different applications, such as knowing that a specific wavelength of electromagnetic energy can be used to detect oil spills. The technique is common in applied remote sensing where thematic information is extracted directly from the imagery and new knowledge is generated (Jensen, 2005). As documented by Curran (1987), technological reasoning places the emphasis on design and is driven by the motivation of human need. This approach is particularly relevant to this thesis, where there is a human need to detect and prosecute illegal oil discharges, hence the need to design a new remote sensing method to address the legal requirements. Singh (1995) discusses the use of different types of airborne methods for oil spill detection. Technological reasoning is shown in this paper, where the author emphasizes the need for optical sensors to potentially reduce the impact of oil pollution, either accidental or intentional.

The first operational satellite-based oil spill monitoring was developed in Norwegian waters in June 1994 (Wahl *et al.*, 1994, Pedersen *et al.,* 1996). Johannessen *et al.* (1995) demonstrated the first version of a SAR classification routine for oil slicks to be used in operational ocean monitoring. Fusco and Vizzari (1998) illustrated a pre-operational oil pollution monitoring system for the Mediterranean Sea using SAR imagery. The Marine SAR Analysis and Interpretation System validate marine products derived from SAR imagery by using other *in-situ* measurements. European countries developed operational air and space-borne remote sensing monitoring procedures. Much of the work has occurred in the North and Baltic Sea and used a variety of airborne sensors to validate satellite SAR in combination with GIS databases of oil slick look-alikes (Tufte *et al.*, 2004).

I-STOP became part of the operational division of the Canadian Ice Service on November 1, 2006. This division has considerable experience analyzing remote sensing data and issues over 5,000 images a day to ice and marine clients (DeAbreu *et al.*, 2006). This operational program applies a technological approach and deductive reasoning where all of the existing knowledge of SAR slick detection is being used to find and validate new oil slicks.

Other authors have further investigated automated detection algorithms to distinguish oil slicks from look-alikes and to validate SAR slick detection. Fiscella *et al.* (2000) evaluated a dataset containing 80 oil slick samples and 43 natural samples showing similar oil slick features and found that more than 80% of samples were correctly classified. The reliability of this method was tested with a different dataset and similar results were obtained in distinguishing oil spills from look-alikes. Brekke and Solberg (2005) discussed Kongsberg Satellite Services manual approach to oil slick detection and with a dataset of 17 verified oil slicks had 88% classification accuracy.

The methods described above use one or more visual interpretation elements, such as tone, shape, size, length, location, orientation, type of edge, texture and backscattering contrast. In addition, these methods include the addition of other contextual information, such as wind, currents, weather or aerial surveillance to help validate oil slicks. Most methods using C-Band SAR imagery, such as ERS and RADARSAT convert values to calibrated sigma nought, which is the measure of the radar signal's strength the Earth's surface backscatters, usually expressed in dB. Bern *et al.* (1993), Brekke and Solberg (2005) and Ivanov *et al.* (2002) used filtering to minimize speckle of the imagery but recommend high-pass filters to preserve edges in the final stage of the analysis. Furthermore, all communication of final results is via an analogue copy of the SAR image showing the oil slick, with some using latitude and longitude grids and sigma nought values. These authors all identified or validated oil slicks on SAR imagery. However, there are not many documented accuracy values due to inadequate validation datasets. These papers further prove Robinson and Ufermann (2003) statements about how there are not enough sufficient oil slick occurrences to perform objective validation of SAR slick detection.

6 INTERPRETATION CRITERIA FOR LEGAL USE

In this section, the steps of visual interpretation of oblique aerial photographs and SAR imagery are compared in order to establish the legal requirements needed for use as evidence.

6.1 Authentication Based on Image Interpretation

The authentication requirement is met by showing how the processing steps are followed when conducting the visual identification of oil slicks using standard practices in the creation of the final product and that legal guidelines have been followed. The principles of image interpretation have been developed and proven through 150 years of experience (Estes *et al.*, 1983; Kelly *et al.*, 1999; McGlone, 2004).

The main elements used when visually interpreting photographic images are size, shape, shadow, tone, texture, pattern, site and association. The image interpretation process contains primary (first order) elements, such as location or tone or colour, and secondary, which is the spatial arrangement of tone and colour (Figure 6-1). The higher, more complex order elements are site, situation and association that are often based on different search methods, such as using collateral data, convergence of evidence and multi-concept interpretation. This image interpretation method is compatible with the legal requirements for authentication, considering it provides the most comprehensive and exhaustive list of image interpretation elements presented in a logical progression and illustrates interconnectivity. It is a hierarchical structure where all of the decision making steps are clearly outlined in a logical order that documents the creation of a final product for the court (Konecny, 2003).

Once the photographs are deemed relevant, the next step is to show that the photographs depict the target area and that the photographs are in their original form. SAR satellites have been used in oil spill detection programs in Europe since the early 1990s (Bern *et al.,* 1993). These types of satellites operate in the microwave portion of the electromagnetic spectrum (1 mm to 1 m) as previously shown in Figure 1-1. The same image interpretation method may be applied to both photos and SAR images. However, the results may be different because the technologies are different.

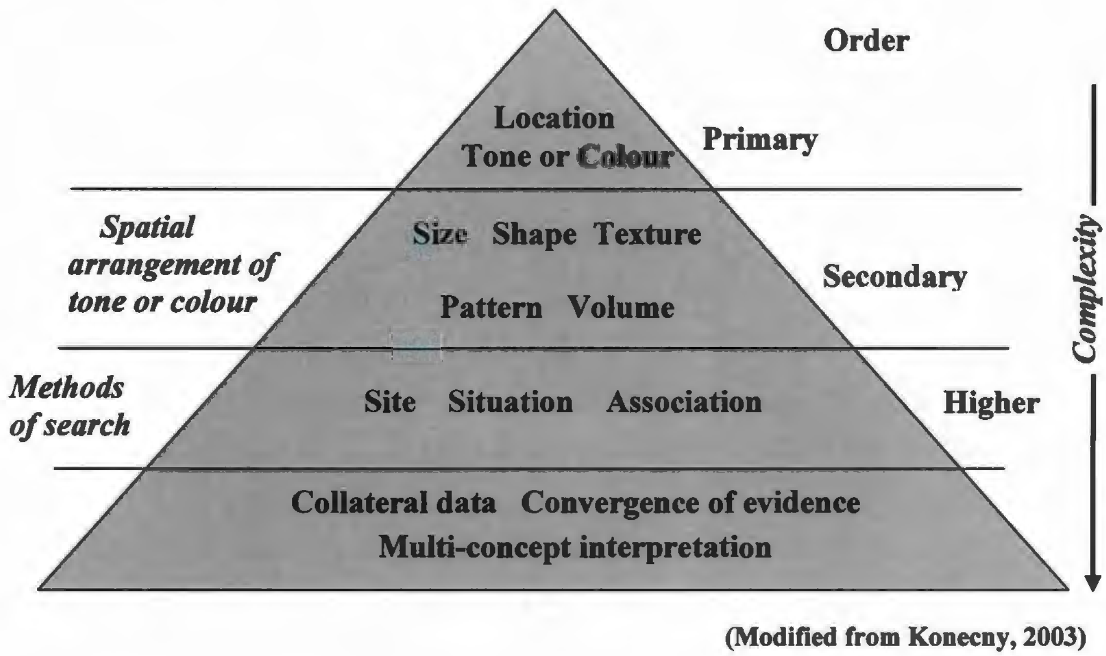


Figure 6-1 Elements of image interpretation

6.1.1 Interpretation Criteria for Oil Spills

Konecny (2003) (Figure 6-1) shows the image interpretation steps used to visually detect oil slicks on oblique aerial photography and SAR imagery. Many technical papers discuss the general parameters of oil identification from aerial surveillance. As part of this thesis research, a comparison of the image interpretation elements that are documented in each aerial surveillance handbook, as previously described in Section 2.2.1, was performed. This in turn illustrates the authentication process for the presence of oil on the ocean.

6.1.1.1 Location

The first interpretation element is the location of the oil slick. The location information provides the ability to spatially link the oil slick with other pieces of evidence. There are two types of spatial location, absolute and relative. The absolute location is the spatial location given in relation to an established coordinate system, such as latitude and longitude, while the relative location is given in relation to surrounding identifiable features, which may or may not themselves be georeferenced (Jensen, 2007). Geometric correction or georeferencing establishes an absolute location by assigning the image's pixels a known geographic co-ordinate. An example of a relative location is to state that an oil slick is located in the vicinity of a ship or shipping lane.

An oblique aerial photograph is documentary proof that a potential oil discharge occurred in a certain location. The absolute location of an oil slick within a vertical aerial photograph can be calculated based on the GPS location of the aircraft when the photo is taken. This allows for calculation of the latitude and longitude of the oil slick and any other features of interest within the photograph, such as a ship. SAR satellites have on-board GPS units which also record the absolute location of each image. This information can be extracted from the image metadata. The relative location can be obtained by observing the surroundings of an alleged oil spill and reviewing the documentation of existing shipping lanes, or other observable targets such as ships.

6.1.1.2 Tone or Colour

Tone is the relative brightness or colour of objects in an image. O'Neil *et al.* (1983) demonstrated that in the visible region of the electromagnetic spectrum, oil has higher surface reflectance properties than water. In colour aerial photographs, oil appears as a bright silvery sheen that reflects light over a wide spectral range. However, as the thickness of the oil increases the appearance of oil on water varies from a silver-grey to brown. For example, the tone on aerial photographs represents the proportion of reflected light which originates from the sun, while on a radar image the tone is a measure of backscattered microwave energy.

Visual detection of oil slicks is generally done by trained observers on surveillance aircraft, who first identify the presence of oil on the ocean surface and then take oblique photographs as potential evidence that can be used in court. The most direct method of oil spill remote sensing is the observation from aircraft, which uses the visible range (red, green and blue) of the electromagnetic spectrum (See Figure 1-1). Aircraft surveillance is only feasible when there is good weather and photographs can only be taken during daylight hours.

Oil on the ocean's surface reduces surface roughness and calms the water producing a 'slick.' An oil slick is caused by two mechanisms: the suppression of capillary waves by the oil film, which acts as a membrane between the wind and water and dampening of the propagation of larger waves (up to 10 m wavelengths) by thicker oil layers (in the mm range) (van Kuilenburg, 1975).

With visible sensors, the contrast from the oil spill related suppression of capillary waves (ripples on the ocean's surface with wavelengths of less than a few centimeters) is typically low and varies with changing lighting conditions. However, if an oil slick is viewed within the sun's glitter pattern at an angle that is reflected by the high wave slopes of the capillary waves of the slick region, then the slick will appear dark against a bright background. Such observations can only be made within a narrow time range when there are clear skies (O'Neil *et al.*, 1983).

The challenge of detecting an oil slick in a SAR image involves first, the visibility of the oil slick in the SAR image under different environmental conditions; second, the variation of SAR signatures from different oil types and the time the oil slick has been on the ocean surface; and, third, the discrimination between oil slicks and other features such as "oil slick look-alikes" (Bern *et al.*, 1993). The most important environmental factor in SAR oil spill detection is sea state, and the optimum wind speed at which oil slicks can be detected in SAR imagery varies according to the literature. Most research indicates that it is difficult to detect oil in wind speeds greater than 10 m/s, but this value may change depending on the type of oil, age and thickness. This also applies to aerial photographs. It has also been found that if the wind speed is too low, oil will also not be detected. The weathering of oil also affects the ability to detect oil slicks. The longer the oil is on the ocean's surface, the more time it has to dissipate and disappear. Oil spill look-alikes include areas of low wind speed, natural films from microorganisms, or wind shadows (Bern *et al.*, 1993). There are a number of other features that can appear like slicks. These include internal waves, freshwater streams on the seawater surface, ship wake scars, and frazil or grease ice (O'Neil *et al.*, 1983). To an untrained observer many other phenomena can appear to be hydrocarbon sheens, such as outflows of fresh water at stream mouths, wind sheens, turbid water, debris in riptides and rafts of pollen. Oil slick look-alikes can also include cloud shadows, ripples on the ocean, and colour differences in adjacent water masses, suspended sediment, floating organic matter, seaweed, algal or plankton blooms, sea grass and coral patches in shallow water, and sewage and industrial discharges (ITOPF, 2001). These features have a similar tone or colour as oil. Furthermore, there are often occurrences of natural oil seeps, which may appear as dark bubbles or circles on the SAR imagery. These factors indicate the possibility of false alarms or "look-likes" when interpreting SAR imagery and visual verification using airborne techniques is often necessary.

Crude oil and refined hydrocarbon products form sheens that refract light in many colour schemes. The refraction of light through the sheen results in colours from which the oil's thickness can be identified. A rainbow-coloured sheen, such as diesel can have a thickness of 0.00015 to 0.00030 mm. Thinner sheens are silvery or gray and thicker sheens have dull colours. Sheens thicker than a few thousandths of a millimeter typically appear to be a similar colour as the originating substance. Bilge fluid, such as oil and water typically appear as sheens rounded in shape with dull to rainbow colours. They may show brown froth or streaks from the fuel and lubricants. Experienced oil observers can detect the likely source of the oil based on the sheen from the colour, luster, shape and location of the slick. Previous knowledge of the local waters and wind patterns along with changes in the observer's relative angle to the sun help to identify these false sheens (ITOPF, 2001).

The colour of different oils released at sea can change as a result of weathering processes. Even though the oil may form a continuous slick, it usually breaks into fragments and windrows mainly due to circulation currents and turbulence. As the oil spreads and the thickness lessens, it changes in appearance from black or dark brown to patches of iridescent and silver sheen on the edges of the slick. Alternately, some heavy fuel oils are often viscous and tend not to spread, but form rounded patches with little or no sheen. The *Bonn Agreement* Handbook oil colour codes include sheen (silvery/grey), rainbow, metallic and true colour. The ITOPF oil codes include oil sheen (silver), sheen iridescent (rainbow), brown to black and brown/orange (ITOPF, 2001). The CCG also use similar colour codes.

The overall appearance of the oil slick is a determining factor in estimating the thickness of oil. This includes the discontinuous true colour and true colour codes, as shown in Table 6-1. In the Bonn Agreement Aerial Handbook, there is a standardized procedure provided to calculate the volume and area of oil slicks. ITOPF also documents that the appearance can provide an approximate thickness measurement, which can also be used to provide volume estimation. Sample guidelines for thickness and volume estimates from the Bonn Agreement are provided in Table 6-1.

Table 6-1 Guide to estimating thickness and volume of oil

Description - Appearance	**Layer Thickness Interval (μm)**	**Litres per km^2**
Sheen (silvery/grey)	0.004 - 0.30	40 - 300
Rainbow	0.30 - 5.0	300 - 5000
Metallic	5.0 - 50	5000 - 50,000
Discontinuous True Oil Colour	50 - 200	50,000 – 200,000
Continuous True Oil Colour	200 to > 200	200,000 - > 200,000

(Bonn Agreement, 2004)

SAR sensors detect oil on the ocean indirectly through the dampening effect on the wind-generated short Bragg (wavelengths measuring a few centimeters) scattering of the capillary waves (i.e. Bragg waves), which at oblique angles are the main backscattering agents of the radar signals. Consequently, the oil slicks appear as dark patches of reduced backscatter on the SAR imagery (Alpers and Huhnerfuss, 1989).

Tone is also the main feature to identify oil slicks and with digital SAR images, the tone can be used to highlight the appearance of the slick in a digital image. Black and white tones are interpreted from single polarization radar images due to the fact that it is single band data (Figure 6-2). Digital imagery also provides an opportunity for further analysis, such as classification, statistical analysis and histogram distribution review.

C-Band SAR, which is on board RADARSAT-1 and ERS satellites, have a wavelength of 5.6 cm and therefore directly correspond to the length of Bragg waves. Cox and Munk (1954) discovered that the interior of a dense slick of length 30 cm or less has a very low backscatter cross-section and its detection is dependent on the ability to distinguish between other potential causes of low backscatter. Along with the visual identification of a dark tone, radar backscatter cross-section values are also used to help identify oil slicks. The potential to detect oil spills using radar backscatter measurements has been widely reported (Huhnerfuss *et al.*, 1981; Johannessen *et al.*, 1994; Konings, 1996; Martinez and Moreno, 1996). A major problem with oil slick detection using SAR and oblique aerial photographs is that microwave backscatter values for oil are not unique (Hovland *et al.*, 1994). Espedal (1998) conducted research into slick properties and reported that oil spills produced a backscatter range of 0.6 db to 13 db and natural oil films were 0.8 db to 11.3 db. In addition to overlapping db values, both features have the same tone and visually appear the same. Most researchers (Brekke and Solberg, 2005) convert the original digital numbers (DNs) in the image to either beta or sigma nought, when performing oil slick detection. A digital number is typically value between zero and 255 assigned to each spatial pixel in a file representing the brightness levels of an image. Beta nought is the radar brightness coefficient, represented by the greek letter, ß°.

The following formula is used to convert original DN values to beta nought values ($\beta^{\circ}j$) using the ScanSAR Narrow beam mode with pixel value j

$$\beta^{\circ}j = 10 * \log 10[(DNj^{2} + A3)/A2j]\,dB \qquad (6.1)$$

Where DNj is the digital number for the magnitude of the jth pixel, A2j is the scaling gain value and A3 is the fixed offset (RADARSAT International, 2000).

6.1.1.3 Shape, Texture and Pattern

The secondary elements of the image interpretation process (See Figure 6-1) are the spatial arrangement of the tone or colour, including the shape, texture and pattern. The next interpretation feature used to identify an oil slick is the two-dimensional shape. Both in aerial photographs and SAR image, the long, linear shape is the key feature to the identification of oil slicks. However, rounded and windrow shapes are caused by the interaction of local winds and waves on oil slicks. Figure 6-2 provides an illustration of typical oil slick shapes.

Figure 6-2 Oil slick shapes

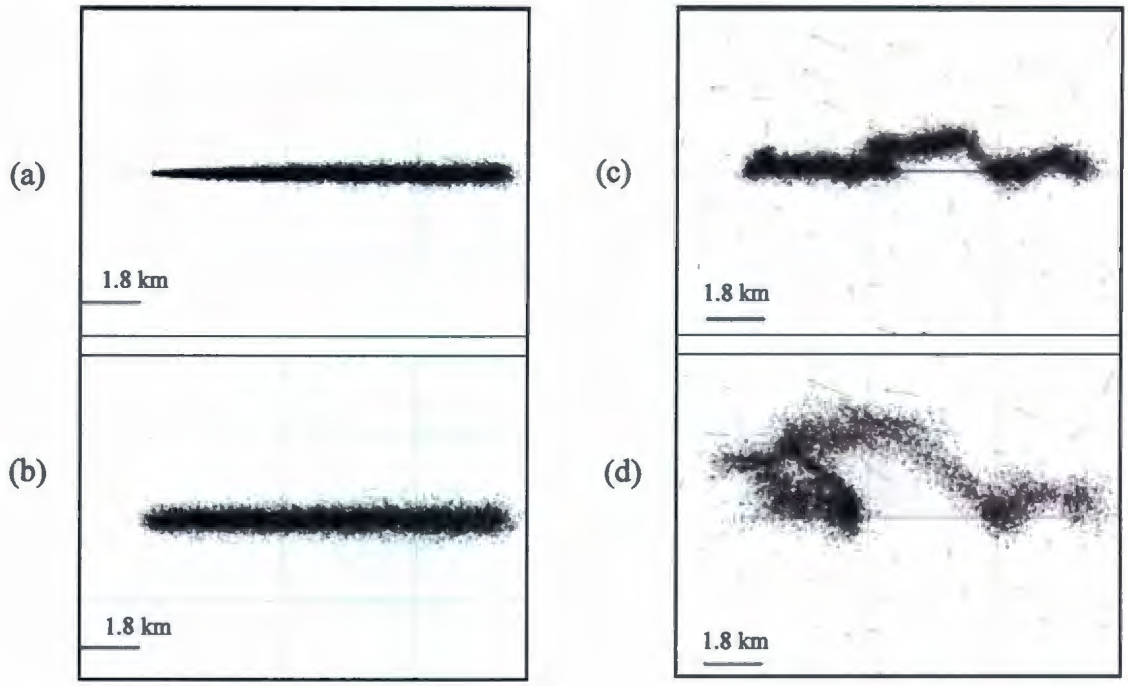
Hollinger and Mennella (1984) conducted sea experimental tests of controlled spills and found that even after several hours of discharging, approximately 90% of the oil remains in its thick parts, which only cover 10% of the total surface area. Typically, ships discharge their oil bilge water while on route to a particular destination, hence leaving behind linear shaped slicks. These are the same linear features that are seen in the oblique photographs except they are taken at a different scale than SAR imagery. This linearity is the most widely identifiable feature when attempting to detect oil slicks in SAR imagery. In an ideal situation in a calm sea, a ship discharging along a straight course will result in a straight line, while a curved path will produce a curved shape.

A visual observer uses changes in texture of the surface and pattern recognition to identify slicks on the ocean's surface. Texture of the ocean can be a determining factor in the visual detection of oil. The majority of oil slick textures in aerial photographs are heterogeneous (mixed), with some homogenous smooth textures. The texture of oil slicks is typically a continuous smooth feature on aerial photography and SAR imagery. The smooth texture that the oil slick creates as it dampens the ocean helps to identify it as a potential slick.

Pattern is the spatial arrangement of objects in an image, which can be described as continuous, random or systematic. There are continuous and discontinuous patterns in the oil colours when visually identifying them on aerial photographs. However, in an SAR image, only the continuous dark tones within the oil slick itself can be identified.

When a spill is detected, with SAR, at the exact time of discharge, the slick will be an elongated narrow V shape at the fresher part, due to the different spreading time along its length, (Figure 6-3 (a)). However, after a short time the oil may disappear, due to the spreading caused by surface waves and currents. This process assumes a 15 knots straight course with seven tons of fuel oil being discharged, calm seas with a spreading rate of 0.6 m^2/s. The overall shape of the slick will be an elongated parallelogram with a constant discharge rate (Figure 6-3 (b)). Despite laterally uniform current and wind on the ocean's surface, the initial general geometric shape will not change significantly during the first few hours. However, only the spill position will deflect due to the route of the discharging ship. Conversely, the situation is different if the spill crosses the varying surface currents and wind fields, which alters the spill geometry, but still keeps some degree of linearity. However, this depends on the strength of wind and current fields and the age of the spill (Figure 6-3 (c) and (d)) (Hollinger and Mennella, 1984).

Pavlakis *et al.* (2001) studied the value of using satellite SAR to monitor illegal vessel discharges in the Mediterranean Sea. The analysis was carried out on 1600 ERS-1 and 2 SAR images collected during 1999. Various shapes and sizes of illegal ship discharges were extracted from the SAR images. A total of 1638 confirmed spills were found and the various shapes are presented in Figure 6-4. The majority of detected spills were linear in shape, either straight or angular. The oil spills were divided into five classes: narrow straight linear spills with tapered front; straight, linear without tapered front; angular spills with tapered front; distorted broad spills without tapered front; and amorphous.



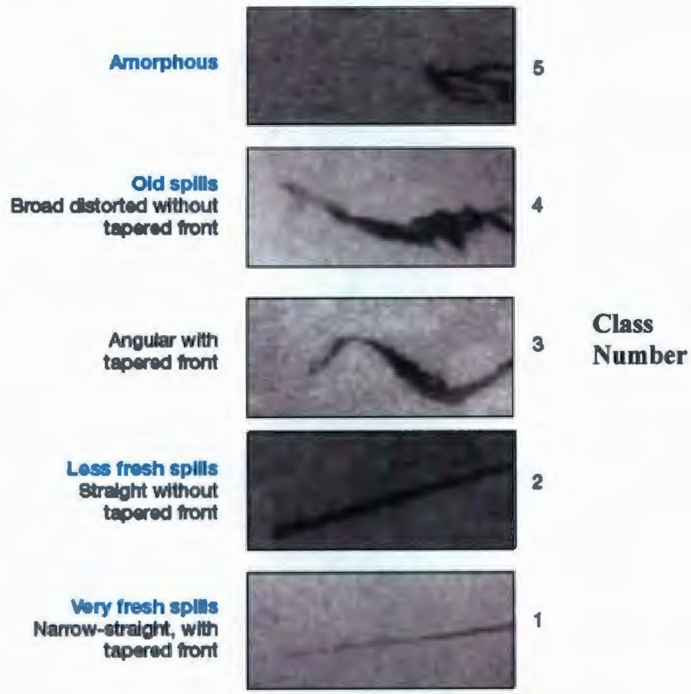
(Hollinger and Mennella, 1984)

Figure 6-3 Spill simulation of ship discharging at 15 knots straight course (a) at the end of discharging and (b) 2 hours after discharging, (c) spill shape in random currents, 1 hour after discharging and (d) 3 hours after discharging.

The first two classes indicated fresh spills. The third class also showed a fresh spill or discharge, but with a maneuvering ship or spilling over a long time, with varying wind and current conditions. The fourth class represents old spills.

6.1.1.4 Dimensions

The dimension allows for quantitative and relative size measurements that can be used to identify features in the image. The most common measurement parameters are length (m), width (m), thickness, area (m^2) and volume (m^3) (Jensen, 2007). Dimensions of an oil slick can be calculated from an oblique aerial photograph and a SAR image, but different methods apply to each.



(Pavlakis *et al.*, 2001)

Figure 6-4 Shape classification of illegal ship discharges

The size of an oil slick can be determined based on the scale of the aerial photograph. The focal length is the distance from the middle of the camera lens to the focal plane or film (Lillesand and Kiefer, 2000). The optical axis of an oblique photograph is inclined more than 10 degrees from nadir, which captures features in a perspective view given by high or low oblique photographs. Consequently, the distance between the camera and the target (ocean surface) increases throughout the photo as compared to a vertical photograph in which the scale is assumed constant. The scale for an oblique photograph is calculated from Equation 6.2, which accounts for the camera's angle adjusted to the incident angle. In order to calculate the scale of an oblique photograph, the flight altitude (A) of the aircraft, the focal length (*f*) and incident angle (α) of the camera are needed (Reeves *et al.*, 1975). The incident angle is the angle that departs from nadir or the line of sight of the camera.

An average scale can be determined.

$$Scale = \left(\frac{f}{A * \sin \alpha} \right) \tag{6.2}$$

There are various methods for calculating the dimensions of oil slicks within the oil surveillance community. The CCG uses a computer system called Airborne Data and Acquisition Management (ADAM) onboard the surveillance aircraft to estimate an oil slick's dimensions including the length, width, area and volume. The ADAM uses GPS measurements (i.e. start and stop positions) and oil colour codes that are manually fed in by the PPO to perform the calculations. An area estimation of an oil slick can be calculated using Equation 6.3.

$$Area = L \times W \tag{6.3}$$

where (L) and (W) are the oil spill's length and width, respectively. The onboard PPO uses codes to determine percentages of an oil colour's appearance. The PPO estimate has to agree with the computer estimate of the amount of oil that is present and the Officer makes and records a final decision on the dimensions of the oil slick. The quantity of the oil spill has to be justified if this evidence goes to court (Personal Communication, Gerry Mallard, 2007).

One problem with estimating the size of oil slicks at sea is that there is a lack of sufficient reference objects for the oil observer to use for size comparison and location. The ITOPF recommends that large slick size estimations should use aircraft speed and time of flight to determine the length of the slick's principal axes.

The volume of oil can be obtained with the following equation:

$$Volume(m^3) = L \times W \times T \qquad (6.4)$$

where (L) is the length, (W) width and (T) thickness of the oil to obtain an estimation of the oil volume that has been released. This is usually expressed in cubic meters.

A georeferenced SAR image normally has a constant spatial resolution over the entire area covered. Therefore, the length and width of an oil slick can be calculated from the radar image and an area estimate can be generated just as with an aerial photograph. Therefore, an area estimate for the slick can be determined by multiplying this value by the number of pixels identified as part of the oil the slick. A second method to calculate the area of an oil slick from a digital image is by using remote sensing software to digitize a polygon delineating the extents of the affected area and extract the corresponding number of pixels or area value.

As with the aerial photographs, the length, width and area can be estimated from the SAR image. However, a volume estimate from the radar image requires supplementary visual or photographic means of documenting the colour of the oil.

6.1.1.5 Site, Situation and Association

Site, situation and association are higher orders of image interpretation elements that can be obtained from both an aerial photograph and a SAR image. Site is the unique ocean environment in which the oil slick is located. An oil slick located within, or in proximity to, a shipping lane is clue to linking the discharge to a ship.

The situation element which can help to identify an oil slick is the orientation of a ship relative to the slick. A situation element documented in the Transport Canada SOPs points out that when a vessel sails through an existing slick, the oil is separated and displaced by the passage of the vessel (Transport Canada, 2007).

Association is the relationship between an oil slick and a potential ship(s) in the general vicinity. If the there are bright targets in the same area as a slick, then this association can help to identify an oil slick (Jensen, 2007). However, an oil slick can occur without the presence of a ship. For instance, when natural seepages occur in the ocean or when a ship leaves a location after discharging oil.

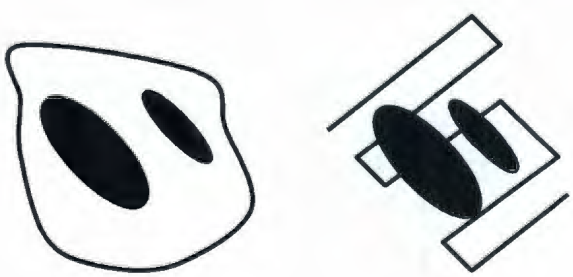
6.1.1.6 Methods of Search

The role for the methods of search (Figure 6-1) in image interpretation is to bring all elements together with other auxiliary data. This final stage integrates collateral data or auxiliary data, convergence of evidence and multi-concept analysis.

With aerial photographs and SAR imagery, numerous environmental features and look-alikes can affect the identification of oil slicks. Sea state and wind speed are the two environmental factors that affect the detection of slicks when using aerial photograph and SAR imagery (ITOPF, 2001; Bern *et al*., 1992).

Both data types have the same look-alikes that can lead to false alarms during the image interpretation. Oil slick look-alikes include natural phenomena that can also dampen the small capillary waves and create dark patches on the ocean's surface. Considering that there are many environmental parameters that affect the ability to detect oil slicks, auxiliary data sometimes are essential to the authentication of an oil slick on SAR image or aerial photographs.

As documented by Taft *et al.* (1995) previous knowledge of the local waters and wind patterns, along with changes in the observer's relative angle with the sun, help to identify these slick look-alikes. Lehr (1994) documents environmental factors that affect the visual identification of oil slicks on the ocean surface, which include sun angle, sea state, cloud cover and aircraft altitude. Sun glitter causes interference where low sun angles in combination with the rough ocean surface reflect solar radiation which can obscure the oil's appearance (Goodman, 1994). It is recommended that the sun should be behind the oil observer when trying to visually identify oil (Bonn Agreement, 2004 and ITOPF, 2001). Oil cannot be visually seen in weather conditions such as thick fog and heavy rain. Also, cloud haze and light reflection off the sea can affect the identification of oil on the ocean's surface. Initial searches for oil slicks in clear weather are normally made from an altitude of between 300 and 450 m, but less than half this height (120 - 150 m) should be used to confirm sightings of floating oil (ITOPF, 2001). A racetrack (circle) search pattern, where all sides of the slick are viewed by flying a racetrack around the slick, is recommended by the *Bonn Agreement*. However, a ladder pattern is recommended by the ITOPF as a most economic survey method, and adjustment of the search pattern may be required depending on the oil distribution and light conditions (ITOPF, 2001). The two search patterns are presented in Figure 6-5. The best position to view the oil is an angle of 40° to 45° from nadir (Bonn Agreement, 2004).



(a) (b)

Figure 6-5 Aerial surveillance search patterns (a) racetrack and (b) ladder.

Auxiliary data minimizes the possibilities of slick look-alikes and can assist with authenticating the identification of an oil slick on an image. For example, as shown in Table 6-2, the local wind speed indicates that there is an optimum speed threshold required to help identify false alarms.

The convergence of evidence is when the image analyst works from the known to the unknown, whereby the knowledge emerging from the process is combined and used to identify an oil slick on the ocean. This process relates to the making of legal proof or defense and is similar to the process which is used to determine the truth in a court case. Pieces of evidence are gathered and used to determine the truth or facts in a case.

Table 6-2 Visibility of slicks in SAR images

Wind Speed (m/s)	Slick Signatures
0	No backscatter from the sea surface, hence no signature of oil slicks
3	No impact on oil slicks, with a high probability of look-alikes due to local wind variations
3 to 7-10	Fewer false alarms from local wind areas, slick still visible and more homogeneous background.
> 7-10	Only thick oil is visible, and thinner oil will be invisible due to dispersion.

(Bern *et al.* 1992; Perez-Marrodan, 1998)

According to Colwell (1997) the most useful and accurate method of scientific image interpretation is multi-concept based and involves performing multispectral, multidisciplinary as well as multi-scale analysis. The use of multiple discrete wavelengths (bands) of the electromagnetic spectrum, called multi-spectral or multi-band is typically more valuable than using a single band. In the context of this research, using colour aerial photographs with multispectral bands (red, green, and blue) provides more information in the identification of oil slicks than using a single panchromatic band.

The multidisciplinary concept is when many different disciplines or methods are used in the image interpretation process and a remote sensing analyst potentially utilizes input from other multidisciplinary scientists. The concept is applicable to this research, where other methods are used as evidence in court to identify oil slicks. These include oil fingerprinting and multi-scale data analysis. Oil fingerprinting involves the matching of oil samples from a slick and a potential ship. This technique involves procedures from other disciplines, such as biology and chemistry.

Multi-scale is also applicable where there are different scales represented with aerial photographs and SAR imagery. Generally aerial photo scales are on the order of 1:2,000 to 1:10,000 (approximately 1 to 5 m resolution), while satellite radar imaging systems provide spatial resolutions of 10 to 30 m. The multi-concept approach helps to strengthen the court case by potentially providing more evidence to help prosecute the case.

6.1.2 Aerial Photography and SAR Standards

As part of the legal authentication process, the oblique photographs and satellite SAR images have to illustrate the specific target area of interest and prove they are equivalent to the information the camera or sensor originally captured. The authentication is addressed by using standard accepted methodologies within each discipline and existing legal guidelines in the preparation of the product.

The steps of the image interpretation process described in the previous Section 6.1.1 are the accepted standard practices for the visual interpretation of oil slicks when using aerial photographs and SAR imagery. Unlike vertical aerial photographs and satellite images, there is no standard for archiving and retrieving oblique photographs. Oblique photographs do not have an indexing standard. Environment Canada and the Canadian Coast Guard have two databases for archiving and the easy retrieval of information about oil spill incidents (Environment Canada, 2002; CCG, 2002b). However, the oblique photographs used in this research were not referenced or archived in a database.

RADARSAT-1 products conform to the Committee of Earth Observation Satellites (CEOS) format standards (RADARSAT International, 1995). The CEOS is an international organization responsible for civil space borne missions designed to observe the planet. Twenty-six members (most of which are national space agencies) and 20 associated national and international corporate organizations take part in the CEOS. The membership includes world's government agencies responsible for civil Earth observation satellite programs and agencies that receive and process data acquired remotely from space. This organization ensures the products are compatible with different satellite imagery users and can be easily exchanged by SAR providers around the world (CEOS, 2007). Authentication of SAR imagery for legal purposes could be established on the basis of the standards developed by this organization, as it has defined a common format that can be traced by the legal community.

Standards are also in place for archiving and documenting metadata. The Canadian Archive of RADARSAT-1 (CARCH) is maintained by the Canada Centre for Remote Sensing, where digital copies of the original RADARSAT-1 images are stored at the Gatineau Satellite Station in Gatineau, Quebec.

Metadata documentation of RADARSAT-1 images is currently done by MacDonald Dettwiler and Associates (MDA) Geospatial Service's computer processors. When MDA analysts visually identify oil on a SAR image, an oil report is produced and can serve as a permanent record (MDA, 2002). Oil spill reports generated by MDA are backed up on DVD-ROM and related email correspondence is archived (Personal Communication, Jeff Hurley, 2007). Oil spill reports can be retrieved from MDA and the original RADARSAT-1 imagery from the CARCH.

During the case study presented in Section 7, the PPO on board the aircraft who took the photographs would have to testify to their authenticity. The CCG and Transport Canada officials in this incident followed their *Standard Operating Procedures* (2007). The *Bonn Agreement Aerial Surveillance Handbook* (2004) and the *ITOPF* (2001) are operational documents for the visual detection of oil that are based on years of experience of detecting oil slicks as well as scientific literature. The SAR image interpretation process is the accepted practice along with other digital standards and these practices should be followed by the image analysts for SAR oil slick detection. The SAR imagery visual interpretation methods for oil slick detection are verified and recognized as they are published in peer-reviewed journals (Wahl *et al*, 1994; Tufte *et al*, 2002; Brekke and Solberg, 2005).

These procedures are at the base of the authentication of a SAR image, considering that the original image is always available to the courts, if needed, and can be checked for authenticity. However, the oil spill product cannot easily be re-generated if the image interpretation process has not been documented completely. The oil spill reports generated by MDA or other groups normally do not provide any specific image interpretation elements that were used during the analyses.

7 CASE STUDY

Programs for oil spill monitoring using SAR imagery have been developed in Canada, Germany and Norway (Turpin, 2003; Tufte *et al*, 2002; Brekke and Solberg, 2005). The I-STOP program developed by Environment Canada, attempts to use the capabilities of the Canadian satellite RADARSAT-1 for oil spill monitoring. I-STOP partners include Transport Canada, CCG, Environment Canada, the Department of National Defense, the Canadian Space Agency and MDA. These programs integrate real-time satellite SAR, where imagery can be delivered to a user within hours after acquisition and then verified with operational airborne surveillance activities. The I-STOP program requires satellite

SAR images to be delivered 1.5 hours after acquisition. This is much faster than the 3- to 5-hour normal delivery mode.

7.1 Background

A RADARSAT-1 image collected under the I-STOP program in 2002 was used in this research. RADARSAT-1 has a SAR sensor and was launched in 1995. This image was the recommended beam mode for oil slick detection, ScanSAR Narrow (Vachon *et al.*, 1998). The incident angle range for this beam mode is 20 to 46° and the width of the image or swath width is 300 km. This image is a combination of Wide 1 (20 - 31° incidence angles) and Wide 2 (31 - 39° incidence angles) beam modes. Beam modes with smaller incidence angles are typically better for oil spill detection because they provide larger swath coverage and produce more backscatter from the ocean. The nominal instrument resolution is 50 m with pixel spacing of 25 m (RADARSAT International, 1995). The microwave energy radar sensors use is largely independent of atmospheric conditions, does not rely on solar illumination and can penetrate cloud cover. RADARSAT-1 is equipped with a C-band radar system that transmits and receives horizontally polarized electromagnetic radiation (HH).

A potential oil slick was identified on the September 8, 2002 image, 275 km south of the French islands of Saint Pierre and Miquelon. This image (Figure 7-1) was chosen for this case study because it was the only image that contained an oil slick verified using aerial surveillance. This case nearly made it to court, but was not prosecuted. A fictional ship name, the *McHugh*, is used in this research to preserve the anonymity of the case. The

RADARSAT-1 image was prepared for use as evidence of oil slick detection and was adapted to meet legal requirements.

(© Canadian Space Agency, 2002)

Figure 7-1 RADARSAT-1 image captured off south coast of Newfoundland with potential oil slick circled.

This image was verified with an aircraft nearly 5.5 hours after the RADARSAT-1 acquisition time (7:30 a.m. NL Time). An oil slick and two other ships were also confirmed to be in the area. The aircraft, dispatched by the Canadian Coast Guard, traveled to the geographic location provided by the satellite image and the oil was visually detected. During this operation, several oblique photographs were taken by the

PPO using a 35 mm analogue (film) colour camera. There were four separate oil slicks observed within the RADARSAT-1 image, and a series of 26 photographs were taken to validate the oil slicks. These oblique aerial photographs are used in the analysis.

During this oil slick incident, there were two documents produced by the different government agencies involved. The Canadian Coast Guard produced a National Environmental Emergencies System (NEES) report (Environment Canada, 2002). It contains the specific date and time at which the potential oil slick was detected, location information, substance details, incident description and contact information. The NEES stores data such as the pollution incident reports as well as historical data for trend analysis. A Marine Pollution Incident Reporting System (MPIRS) report was also produced during this incident. These reports are maintained in the Canadian Coast Guard's national database for collecting and reporting all marine pollution incidents (CCG, 2002b).

MDA performs the image processing and interpretation for the I-STOP program. A geometric correction of the RADARSAT-1 image using co-ordinates from the raw image prepared the image for interpretation. This was followed by the visual interpretation of the brightness values in order to distinguish the potential oil slick from the surrounding ocean background (Personal Communication, Jeff Hurley, 2007). Visual interpretation was used instead of automated classification because interpreters can incorporate context information, such as local wind speed and therefore minimize the possibility of false positives in the analysis. Interpreters assessed the likelihood that the feature might be an oil slick. Confirmation that the feature was in fact an oil slick was only verified by visual inspection from the aircraft. When the oil slick anomaly was detected on the RADARSAT-1 imagery, it was labeled according to one of the four categories listed in Table 7-1 (Turpin, 2003). The category given to this incident was a Category 1B.

Table 7-1 Anomaly categories

Category #	**Description**
Category 1A	Potential oil present with ship attached
Category 1B	Potential oil present with ship in area
Category 2	Potential oil present without source
Category 3	Unsure image is oil

(Turpin, 2003)

The image analysis was performed using GIS software, which allowed the analyst to view a geo-referenced image, with an overlaid latitude and longitude grid, in conjunction with a vector database that shows the oil spill location relative to features, such as land boundaries, shipping lanes, oil platforms, and underwater pipelines. When a potential oil slick is detected, it is digitally annotated on the image and an oil slick report is generated. The report includes the geographic coordinates of each target and possible direction of travel.

7.2 Legal Chain of Custody for SAR Slick Detection

As described by Jensen (2007), the two main types of image processing methods are analogue (visual) and digital. Both of these techniques will be used to illustrate the complete chain of custody procedure for the use of SAR as evidence in court.

The digital image processing steps that are applicable to SAR slick detection include pre-processing, visual interpretation, creation of the oil slick product, validation and final legal oil slick product. The general remote sensing process consists of the following elements: statement of the problem, data collection, data to information conversion and information presentation. The left hand column of Figure 7-2 lists the remote sensing process steps Jensen (2007) suggests. The center and right hand columns indicate how the process is adapted for SAR based oil slick detection.

As part of this case study, the technological parameters for the validation of SAR imagery for legal use and the legal guidelines were incorporated during the processing of the SAR image. This study also included the documentation of the environmental parameters that affect detection, which is part of the validation process needed for evidence. Through this process, the authentication of a satellite SAR image was also established.

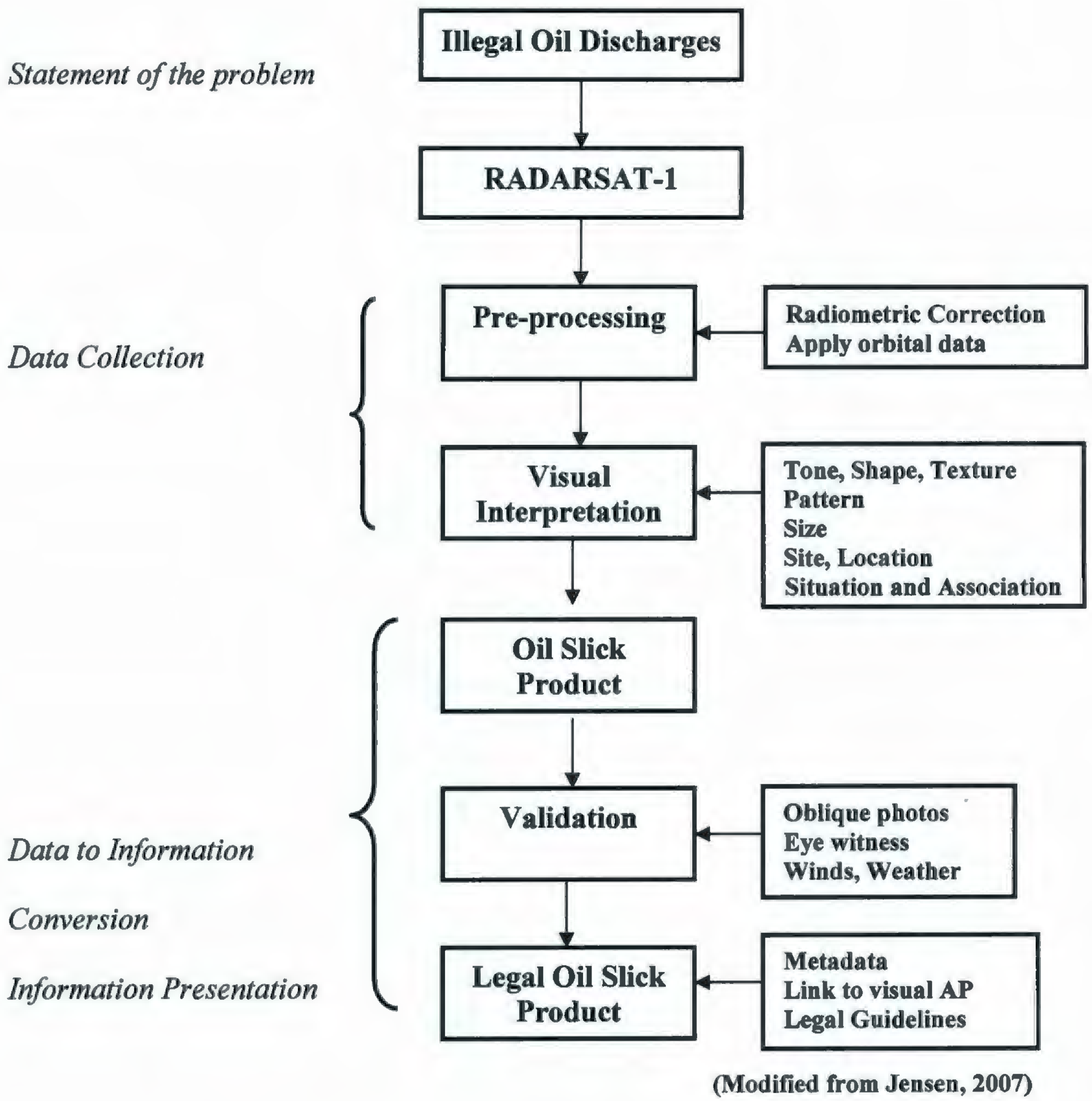


Figure 7-2 Remote sensing process for SAR based oil slick detection

7.3 Pre-processing

In order to prove that an oil slick is present in a SAR image, all the image processing steps need to be documented. Elements of pre-processing include radiometric calibration, geometric correction, image enhancements and filtering. These technical steps are performed and documented during this case study to illustrate their importance for legal use and meeting the legal requirements.

Radiometric calibration is the process whereby the digital values of a received image can be quantitatively related to brightness (reflectivity), phase and location. It also minimizes the noise level. Geometric correction is the application of a standard map projection to an image, in this case a Universal Transverse Mercator (UTM) projection (Jensen, 2007). Image enhancements are often applied to satellite imagery during the pre-processing step to improve the appearance of an image for visual interpretation (Jensen, 2005). Filtering techniques are also used to remove certain spectral or spatial frequencies in order to highlight features in an image.

When satellite images have a large range of incidence angles, such as RADARSAT-1 ScanSAR imagery, the analyst has to account for the decreasing mean radar brightness associated with the increasing incidence angle (Raney *et al.*, 1991). Radiometric calibrations must be applied to the imagery, in order to minimize reduced brightness with range and digital dynamic range requirements that can be expressed as either beta nought (β°) or sigma nought (σ°) (Raney *et al.*, 1994). Calibrated imagery allows products derived on different dates to be compared (Jensen, 2005). Furthermore, all of the SAR slick detection methods in the literature use sigma nought calibrated radar brightness (dB) values in their analysis. Therefore, when using SAR imagery for legal use and the visual detection of oil slicks, one should use calibrated values (either ß° or σ°) and not the DNs from the original RADARSAT-1 image. Figure 7-3 contains a graph of the input, DN values against the output calibrated beta nought values. Even though the pixel values change, the relationship between the DN and the calibrated values is known. The calibrated values are more true to feature characteristics since they are the values recorded directly at the sensor.

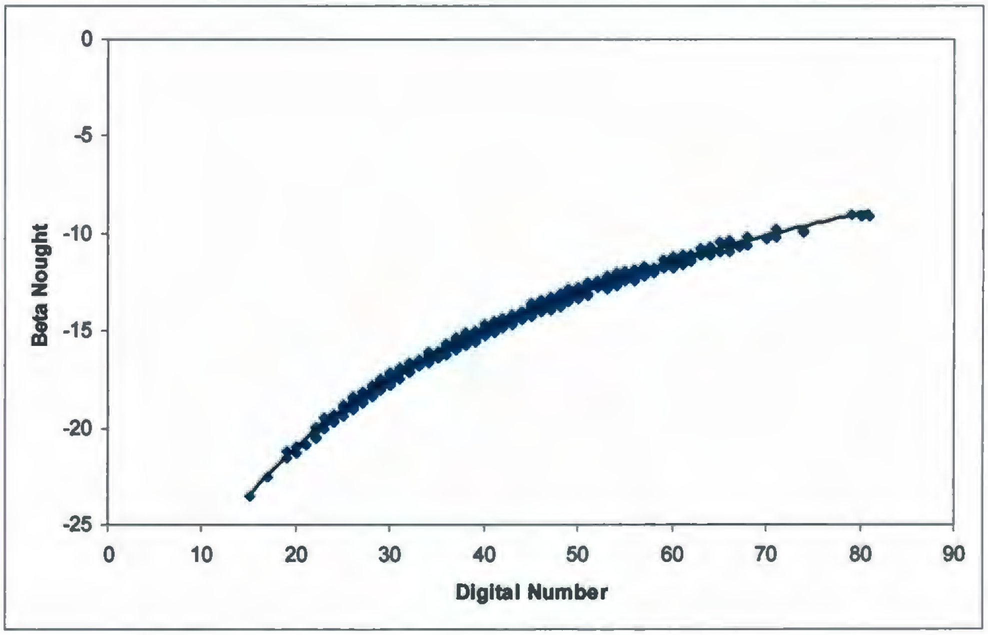


Figure 7-3 Input digital numbers and output calibrated beta nought values.

A look-up table plot for the entire image showing the scale gain as a function of incidence angle values is shown in Figure 7-4. This illustrates the changes in pixel values across an image when the image is calibrated for variation of backscattering across the image range. The gain normalizes backscatter for an ocean attributed as a function of incidence angle. By applying this calibration, the image information content is maintained through backscattering values that are less sensitive to the incidence angle variations across the image range (Figure 7-5).

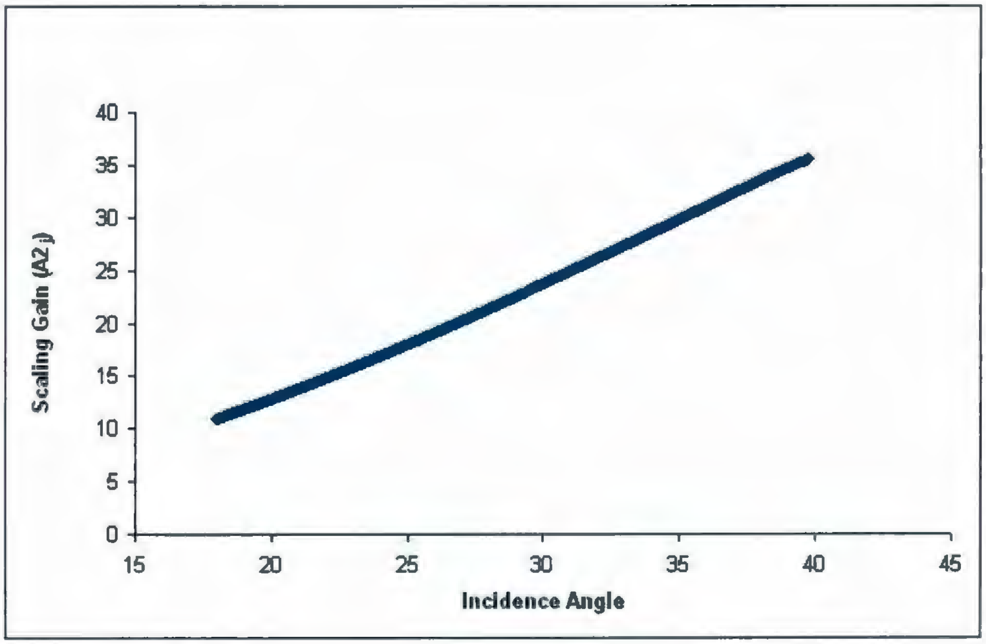


Figure 7-4 Gain scale factor for scanSAR narrow

(a)

(b)

Figure 7-5 Oil slick in original DN image (a) and (b) beta nought image

The RADARSAT-1 image used in the analysis is a path image with an absolute location error that is nominally ±750 m. The image latitude and longitude positional information is added to the first, middle and last pixel of each data line and is documented in the CEOS file. The orbital information containing the UTM map projection and World Geodetic Survey 1984 datum is applied to the image. This projection parameter, when applied to the image, provides positional information to the image needed for legal use and the validation of SAR imagery. For legal use, the orbit file included with each CEOS file should be used to geo-reference the RADARSAT-1 image to ensure positional information has been applied.

Image enhancements can make the image appear more visually pleasing on the computer screen and hence, easier to interpret without changing the original digital numbers in the image file. When using SAR imagery for legal evidence, an explanation should be provided on how an image enhanced on a computer does not change the original image content, only its visual appearance on the computer screen. When an image enhancement is applied, the mathematical relationship used during the procedure should be explained. For example, if a linear enhancement is applied to an image, the minimum and maximum values in the image histogram are uniformly stretched over the entire available output display to enhance the difference in grey levels in the image. As a result, the light toned areas appear lighter and the dark areas appear darker (Lillesand and Kiefer, 2000).

The linear stretch formula that is applied to each pixel is shown in the following formula:

$$DN' = \left(\frac{DN - MIN}{MAX - MIN} \right) \times 255 \qquad (7.1)$$

One type of image enhancement often used to remove speckle from radar imagery is filtering. For illustration purposes, an Enhanced Lee speckle filter was used in the original DN RADARSAT image (Lee, 1980; Lopes *et al.*, 1990) (Figure 7-6). This type of filter is primarily used on radar data to remove high frequency noise (speckle), while at the same time preserving high frequency features (edges). A line transect was drawn through the oil slick on the original image and the (3 pixels * 3 pixels) and (9 pixels * 9 pixels) filter window sizes. The same trends in slick shape and size are evident in all three images. However, each filter lowers the brightness values as shown in Figure 7-7. Filtering has been used by Ivanov *et al.* (2002) and Bern *et al.* (1993) to reduce ocean speckle for oil slick detection. This type of speckle removal from the image does not alter the original image and therefore can be used when presenting radar imagery as evidence with either a 3- or 9-pixel window size.

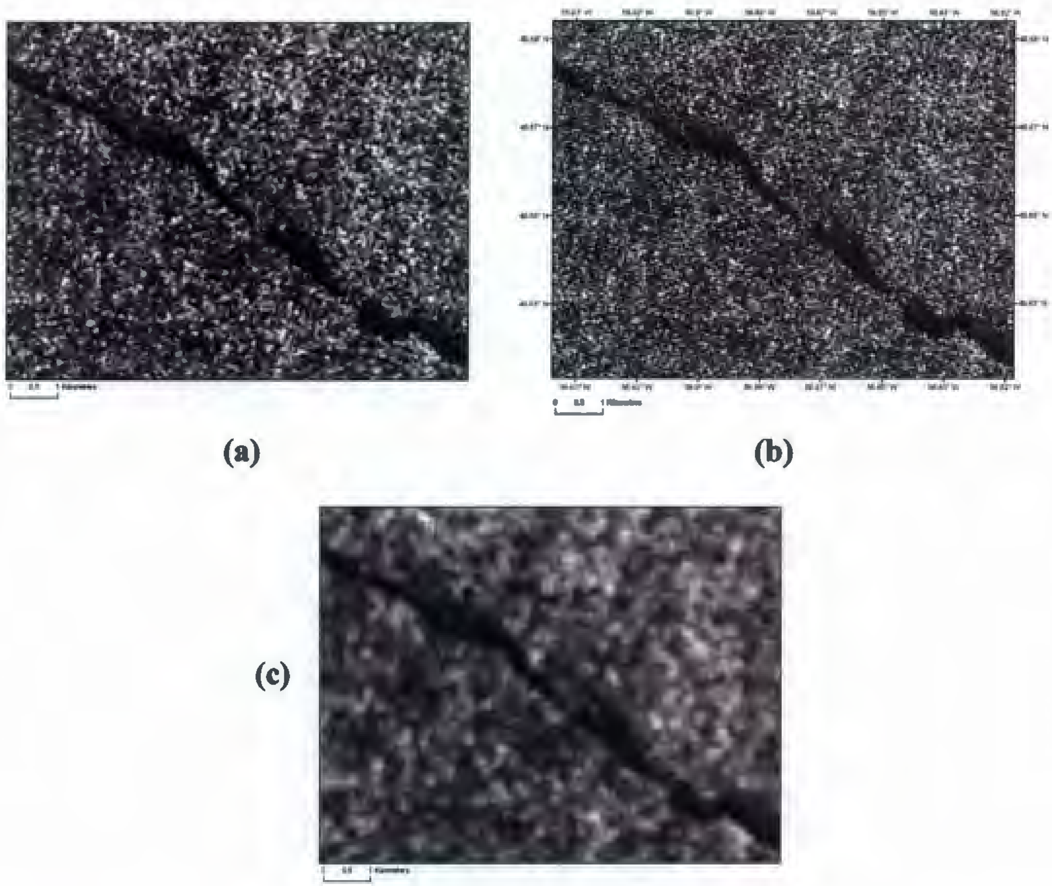


Figure 7-6 (a) Enhanced Lee filtered image (3*3), (b) original image and (c) (9*9 filter).

7.4 Visual Interpretation of RADARSAT-1 Image

After the necessary pre-processing steps are completed, the image is ready for image interpretation and analysis. The visual image interpretation process was applied to the SAR image to identify any potential oil slicks. The image interpretation elements used to identity oil slicks include tone, shape, texture, pattern, site, situation, association, size and location.

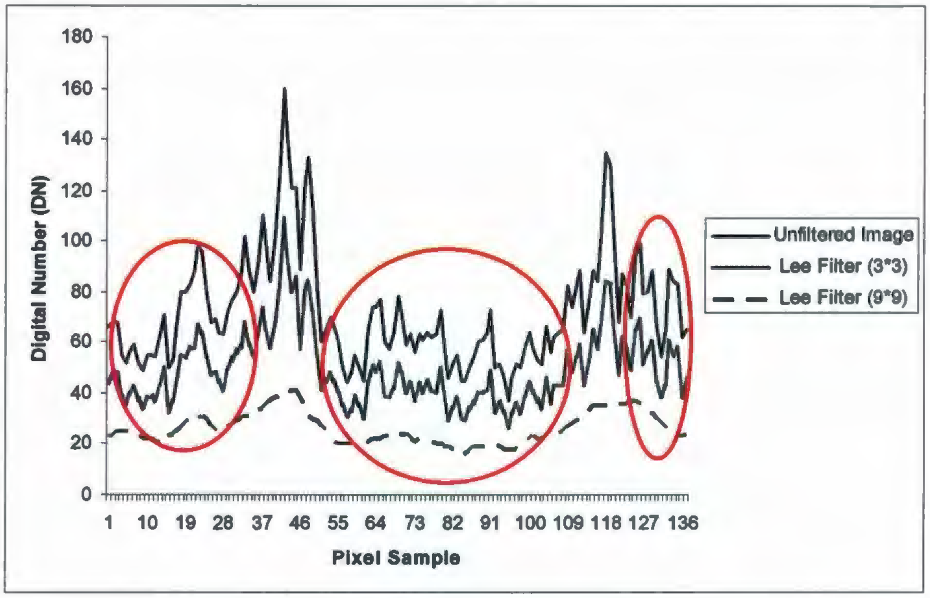


Figure 7-7 Line transect through oil slick on original (unfiltered) image and filtered images. The oil slick areas are circled.

7.4.1 Tone

Several dark toned areas, potentially oil slicks, were identified on the RADARSAT-1 image during the case study. This included areas near the coastal islands of Saint Pierre and Miquelon and in the centre of the image (Refer to Figure 7-8 (a) and (b)). Other dark toned areas in the image are circled and indicated as (c) and (d). Consistent with the change of incidence angle from the near (East) to the far range (West), the image also appeared darker on the left side of the image and brighter on the right side. This is a common characteristic of a SAR image.

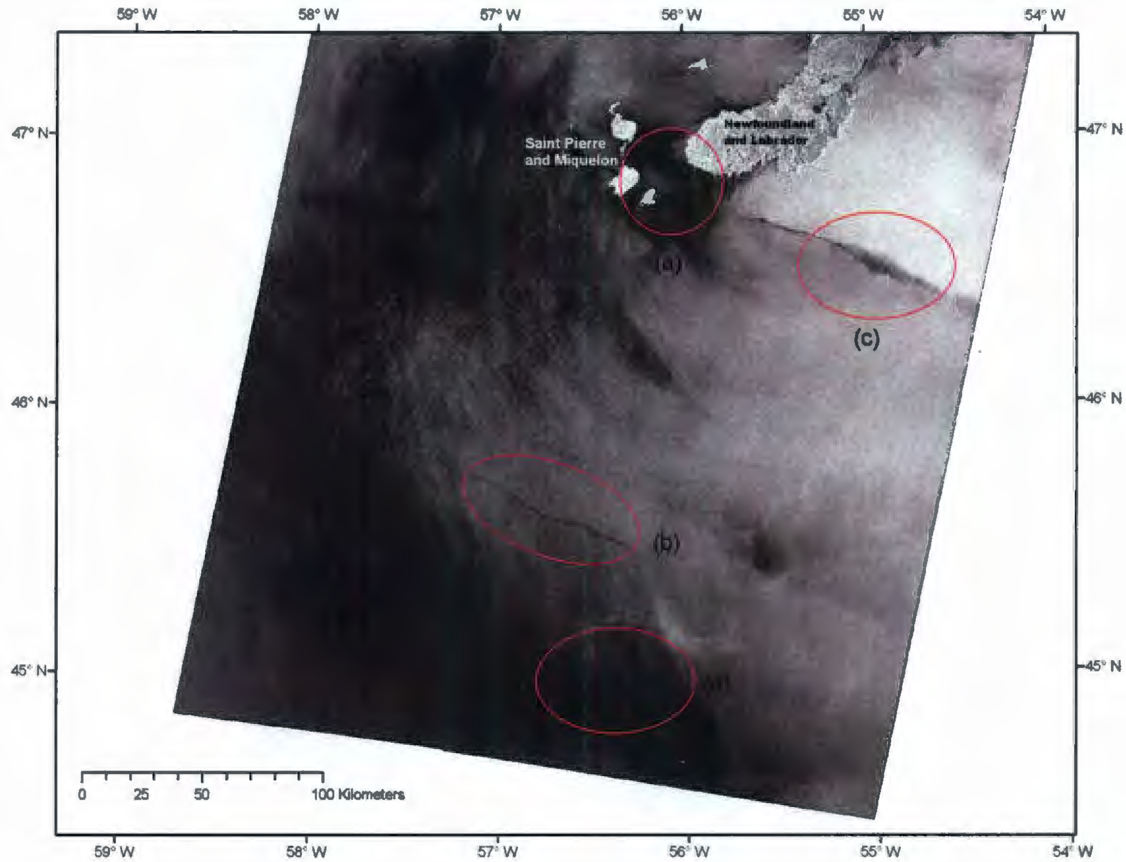


Figure 7-8 RADARSAT-1 image acquired on September 8, 2002 with identified dark tones. Dark tones at locations (a), (c) and (d) are not typical oil slick shapes unlike the linear narrow shape at location (b).

7.4.2 Shape, Texture and Pattern

The dampening of the capillary waves on the ocean and the creation of a thin narrow film smoothing the ocean surface represents the unique characteristics of an oil slick. The shape helps to distinguish which dark toned features could potentially be oil slicks. The shape differences of the dark toned areas are seen in Figure 7-8. The feature highlighted as (b) in the south of the image is long and linear in shape, and the other three areas,

Figure 7-8 (a), (c) and (d) are more circular in shape. Oil slicks from ships are typically linear in shape, such as the probable oil slick observed in this image, Figure 7-8 (b).

There are two main differences between the dark toned, smooth areas near the islands of Saint Pierre and Miquelon Figure 7-8 (a), which are often caused by algal blooms, are large in area (shape) and more circular in shape as compared to the linear feature (b). The dark toned features in the image, labeled (c) and (d) in Figure 7-8 are most likely due to wind effects near the coast and offshore, respectively.

The texture of the oil slick is smooth and homogenous and therefore can be distinguished from the surrounding heterogeneous ocean background. A transect was drawn through the surrounding ocean and the oil slick feature to show the trends that exist in the original, unfiltered image and the two filtered images. The smooth oil slick feature has lower digital numbers than the rough ocean mainly due to lower backscatter produced from this homogeneous (less rough) feature. This trend is evident in Figure 7-9 where the oil slick is located between the 127- to 141-pixel sample values. In this radar image, continuous dark tones within the oil slick itself can be identified and a discontinuous, random pattern of ocean clutter as shown in the Figure 7-9. The oil slick smooth texture forms a continuous pattern of dark toned pixels.

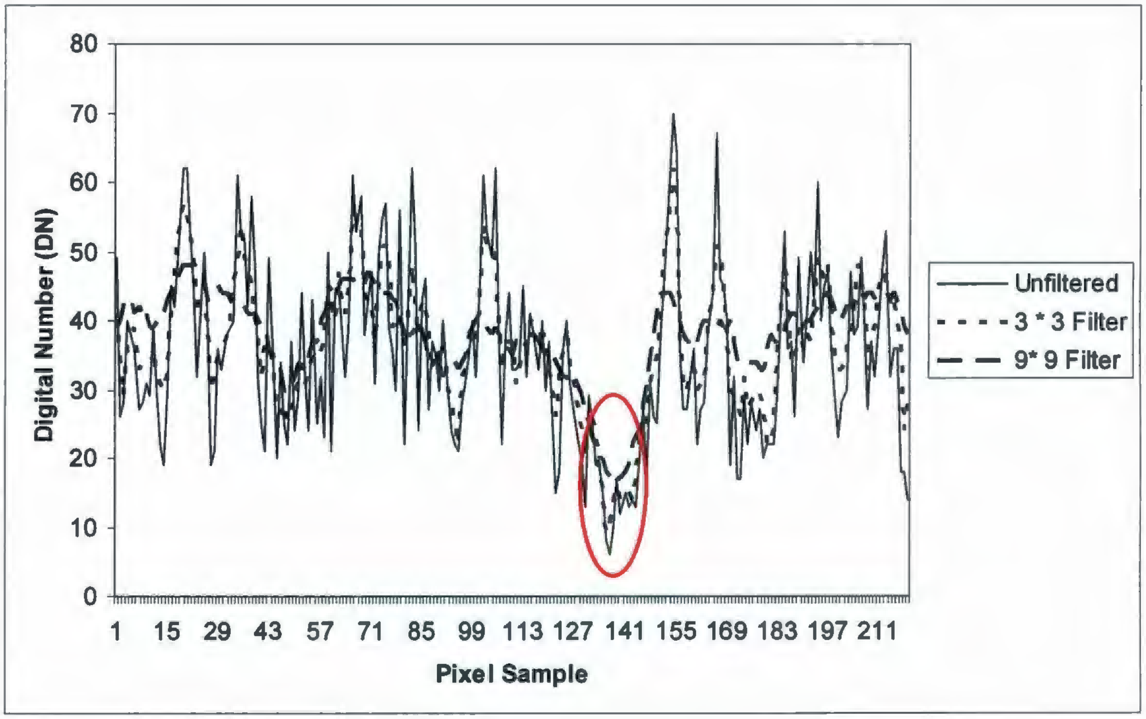


Figure 7-9 Line transect through smooth (oil slick) and rough (ocean) features in original (unfiltered) and filtered images. The oil slick is circled.

7.4.3 Site, Situation and Association

An identifying site element was the potential oil slick feature located offshore, approximately 150 km from the nearest coastline and in a shipping lane in Canadian waters, shown in Figure 7-8 (a). The situation element included the two bright tone features identified just north of the potential slick. These bright features are possibly two ship targets that were in the general vicinity of the oil slick (Figure 7-10). The ships were oriented north of the slick. However, the ships were not directly aligned with the slick. The association of the ships and the oil slick occurring together is also the association criteria that can be used to further identify the slick.

Figure 7-10 Two potential ship targets (circled) in general vicinity of oil slick

7.4.4 Size and Location

The spatial resolution for this image is 25 m. The length and width of an oil slick was calculated from the radar image and an area estimate using Equation 6.3. The length and width of the slick were measured with a distance measuring tool on a computer screen. The length of the oil slick is 73.5 km and the maximum width is 0.5 km. Thus, the calculated area is 36.75 km^2. The variation in slick width, due to wind and current, was quite visible.

The absolute location of the oil slick was taken from the RADARSAT-1 image. The co-ordinates recorded from the centre of the potential oil slick were 45° 35' 07.05" N and 56° 44' 21.14" W. These co-ordinates were approximately 12 km from the co-ordinates originally provided by MDA during the I-STOP program. Hence, the co-ordinates from MDA were not taken from the approximate centre of the slick. The specific location information of exactly where the co-ordinates were taken from was not provided in the documentation.

7.5 Validation

To validate the potential oil slick identified in the RADARSAT-1 image, collateral data, such as environmental parameters were reviewed as well as data collected from the aerial surveillance mission. The environmental and acquisition parameters include wind speed and direction, sea state, weather, sun angle, viewing angle and altitude. The aerial surveillance data used for validation included high oblique aerial photographs, a Canadian Coast Guard Incident Report or flight report, NEES, MIPRS and the oil slick report (Canadian Coast Guard, 2002a, 2002b; Environment Canada, 2002; MDA, 2002). The following section presents the collateral data used to validate the SAR image and help prepare it as evidence in a court case.

7.5.1 Collateral Data

This section describes the collateral data available that match the RADARSAT-1 image acquisition and identified any gaps in the documentation. Although, a database of potential look-alikes sources, such as the location of oil rigs, known leaking pipelines and bottom seepages can help to decrease the number of false alarms, this information was not recorded for the area.

The auxiliary information was provided through the NEES, MPIRS, CCG flight report and oil slick report recorded during this incident. The weather and altitude at which the photographs were taken was documented in the flight report. However, the wind direction and speed, visibility, sun angle and viewing angle at which the photos were taken and speed of the aircraft were not documented in the flight report for this incident. The visibility, wind and sea state information was also missing from the CCG flight report. The metadata of the photographs were not contained in the flight report. The availability and completeness of these pieces of information affect the detection of oil at sea and are outlined in the aerial surveillance manuals. An overall altitude profile for the flight plan was provided; however, the photographs could not be matched up with specific flight altitudes.

The oil slick report included the geographic coordinates of each target and the direction of travel. The Meteorological Service of Canada (MSC) 12-hour forecasts were used as the sources of wind data and were inputted to the digital polygon shape file of the oil slick created by MDA. The wind speed in the *McHugh* ship incident was estimated to 25 knots, but no wind direction was recorded at the time. The wind speed is within the limit for the detection of oil slicks. Wind direction information for the purpose of this research is complemented by the historical MSC Sea State and Buoy Status Reports. Archive data revealed that the wind speed and direction on that day, near the Banquereau Bank buoy, was 35 knots from the East. The direction of the oil slick drift is consistent with this documented wind direction to the East near Cape Race, Newfoundland.

7.5.2 Oblique Air Photographs Interpretation

When the surveillance aircraft reached the geographic location provided by the SAR image, four segments of an oil slick were found in the general vicinity of the slick. A video taken during this incident showed a ship within the general area of the four identified slicks. A relative location of the four separate slicks was in the open ocean along the shipping route in close proximity to a ship. However, there is no photo which shows the slick in the ship's wake and clear water in front of the ship (bow).

The oblique photographs taken from the *McHugh* ship incident were interpreted to determine the colour, texture variations, shapes, and patterns. Four oil slicks, illustrating several changes in colours, were identified on the oblique photographs. The colour codes from the *Bonn Agreement Oil Appearance Code* (BAOAC) system were used (See Table 6-1). The *Bonn Agreement Codes* were chosen for this analysis because they were the most detailed and descriptive for identifying oil properties.

The aerial photographs consisted of photos of the both the oil slicks and ship present in the area. From the 26 oblique aerial photographs, seven oil slicks were classified as sheen (slivered/grey), three were rainbow colour, and four were metallic. There were also five slicks, which appeared as discontinuous true oil colours and two continuous true colour categories identified.

Linear, rounded and windrow shapes (as previously shown in Figure 6-2) were identified on the oblique photographs. Ten photographs contained linear and elongated oil slicks, five had rounded and six windrow shaped oil spills. The texture of the oil spill identified in two photographs was smooth, with the majority of the other photos revealing a coarse texture due to the surface ripples or currents. The patterns of oil slicks were previously identified as discontinuous and continuous colour codes.

The oblique photographs show all the five *Bonn Agreement* colour classes and all three oil shapes such as linear, windrow and round. Therefore, these photographs are an excellent example of documentation that there were in fact oil slicks on the ocean surface on September 8, 2002 as indicated by the RADARSAT-1 satellite image. Five photographs did not display any evidence of an oil slick. Some of them may have been take from a too high altitude, using a small viewing angle (35° or less) from the horizontal or captured partly facing the sun.

To calculate the average scale of a high oblique photograph from this dataset, Equation 7.2 is used. The values are illustrated in this example by using a photograph from the *McHugh* ship incident (Figure 7-11), where focal length (*fl*) is 35 mm or 0.035 m, the incident angle (α) is 50° and the altitude is 305 m. The oil slick is roughly in the middle of this oblique photo. Therefore, the scale of the oblique photo at 50° is 1/6675. To calculate the length of the oil slick at the 50° incident angle, the following equation is used:

$$Scale = \left(\frac{D_p}{D_a}\right) \qquad (7.2)$$

where D_p is the distance the oil slick covers on the photo and D_a is the actual distance across the slick on the ocean. The length of the oil slick at 50° incident angle is, for D_p = 15 cm, 1001 m, while the width D_p = 1 mm, yields 6.68 m. Thus, the area of the slick is estimated to be 6687 m^2. The photograph only contains one section of the potential oil slick identified on the SAR image and it was not the only photograph showing this linear oil slick segment.

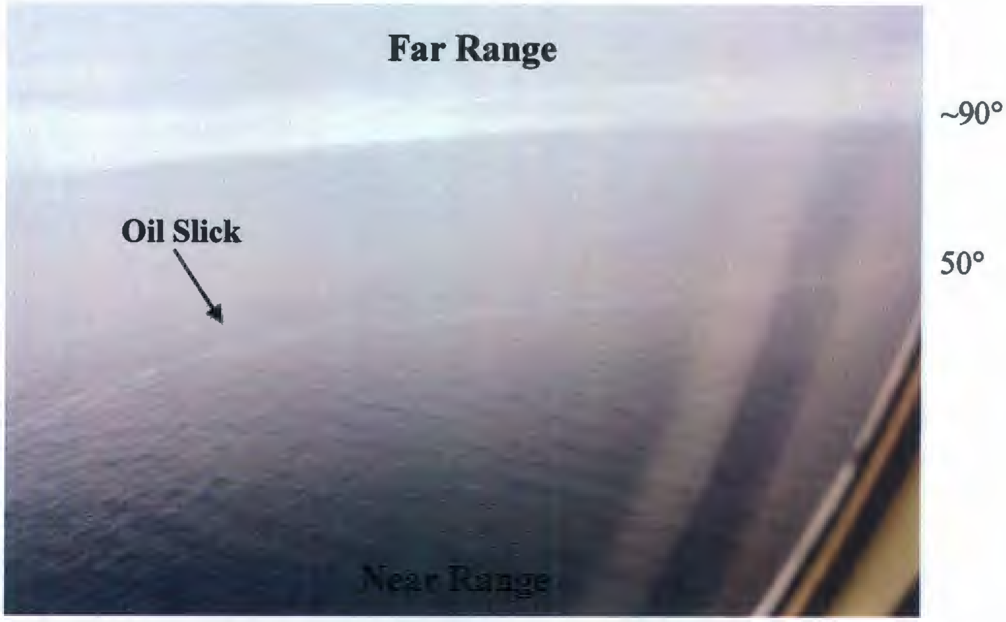


Figure 7-11 High oblique photograph showing change in incidence angle

A total volume of oil spilled cannot be obtained from the oblique photographs, as there was no reference to the location of where each photograph was captured. Hence, the oil spill detected in Figure 7-11 was interpreted to obtain an estimate on the volume of oil that was spilled in this particular photograph. The slick in this photograph is a long narrow sheen, which is silvery grey in colour; therefore, the estimate on the volume of oil released, using the *Bonn Agreement Oil Appearance Codes,* was between 40-300 litres per km^2. Using the area estimate of the slick in the photograph, a range of the volume was calculated to be between 0.267 and 2.006 litres. These values represent only a small portion, included in the colour photograph, of the 600 litres estimate made by the Canadian Coast Guard (CCG, 2002a) during this incident. The area estimate from the RADARSAT-1 image is 36.75 km^2 (Section 7.4.4) This value extrapolated based on the colour photo derived volume estimate of 40 to 300 litres/km^2 yields a total volume of 1,470 to 11,025 litres. The discrepancy between the CCG total volume estimate and the evaluation made from the combination of the aerial photograph and SAR image information may be explained by that the width measurement was made across the widest section of the slick. The oil slick width varies across the SAR image from a few (3 or 4) pixels to 20 pixels (i.e. 0.5 km). On the other hand, it is possible the CCG estimate reported a conservative estimate of the total volume.

The volume expresses the amount of oil that was released and links with an equivalent part per million (ppm) concentration estimate. The legal concentration million of 15 ppm Pavlakis *et al.* (2001) is equivalent to approximately 90 litres of oil (Committee on Oil in the Sea, 2003). The SAR image suggests that this limit was exceeded.

The PPO documented the absolute location of oil slicks from the on board GPS during the aerial surveillance flight. The Canadian Coast Guard also use a digital camera fixed with GPS data annotation on another aircraft to record location information and is better suited for legal documentation. Photographs from the digital camera are automatically stamped with the date, time and geographic co-ordinates. There was a series of 26 colour oblique photographs taken to validate the oil slick, with the first photo being taken at position 45.7740°N 57.0097°W and the last at 44.4577°N 53.9178°W. The photographs were taken at 14:55 and 16:00 Coordinated Universal Time (12:25pm and 1:30pm Newfoundland Time) (Personal Communication, Gerry Mallard, 2007). This location information was detailed on the NEES form with a general latitude and longitude and location description. However, no locational information is referenced on the MPIRS form and only states the "South Coast of Newfoundland." The aerial photographs provided for this research did not have any specific geographic co-ordinates indicated (i.e. stamped) on each photograph. Therefore, the single co-ordinates provided with each oil sighting on the flight report, the oil coverage percentages, and numbers printed on back of the photos were used to estimate of the photo's geographic location. For legal purposes, the same geographic co-ordinates should be listed on all reports to show consistency between the aerial photographs and SAR image.

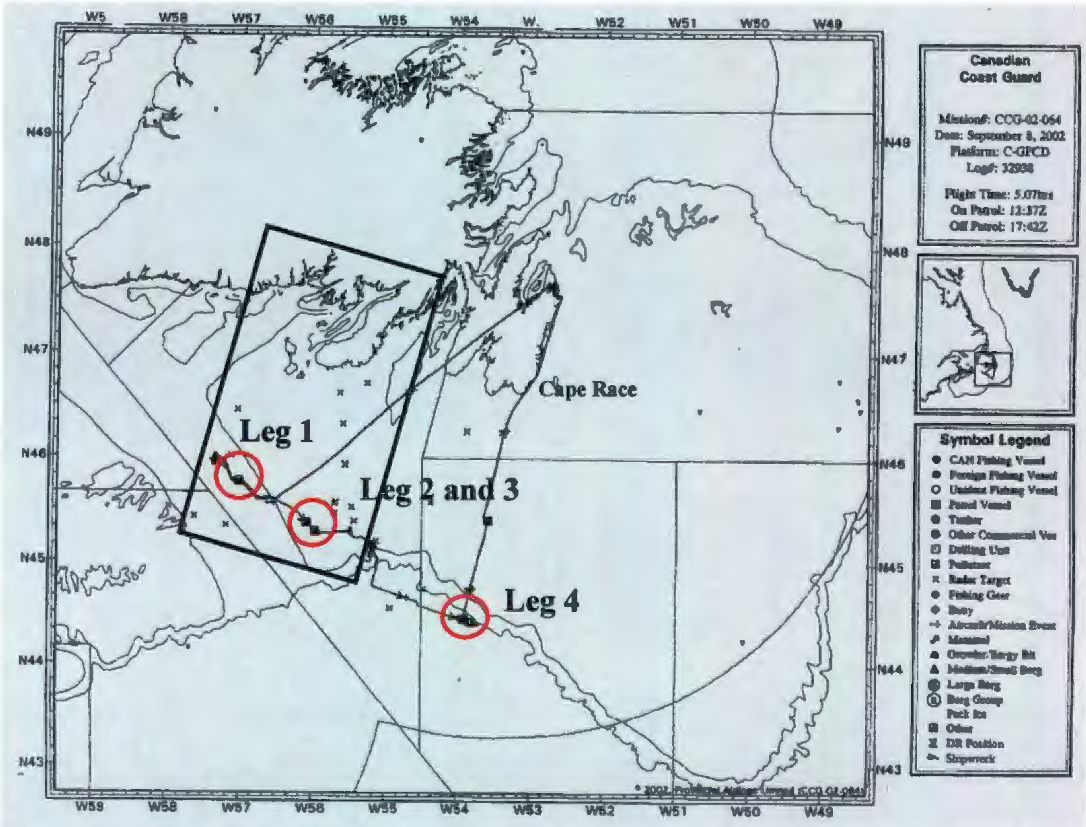
The RADARSAT-1 image was captured at 7:30am NL time and 5.5 hours later, an aircraft was at the location of the potential oil slick. However, there is no documentation in the reports on the section of the oil slick, such as the centre part or edges, the co-ordinates were extracted from. As shown in Table 7.2, the latitude and longitude co-ordinates from the RADARSAT-1 provided in the NEES report were in degrees decimal minutes format (e.g. 45° 33.83' N and 56° 34.23' W). The geographic co-ordinates must be converted to a common format. The GPS co-ordinates provided from the aircraft were in decimal degrees; hence, the RADARSAT-1 image co-ordinate for the oil slick was converted to this format to ensure continuity.

Each oil sighting is listed in Table 7.2 and plotted on Figure 7-12. The points were manually entered into a GIS, and a point vector file was created. The points were converted to UTM co-ordinates to integrate with the RADARSAT-1 image and measure the distances that separate them from the oil slick. The first three of the oil sightings fell within the RADARSAT-1 image coverage; however, the fourth oil sighting (Leg 4) was located south of Cape Race, the most easterly point on Figure 7-12.

Table 7-2 Potential slick spatial co-ordinates

Oil Sightings	Latitude (degree)	Longitude (degree)
RADARSAT-1	45.5638 N	56.5705 W
Aircraft		
Leg 1	45.7740 N	57.0097 W
Leg 2	45.3800 N	56.0825 W
Leg 3	45.2962 N	55.9663 W
Leg 4	44.4577 N	53.9178 W

The aircraft points of the slick were overlaid in a GIS, on the RADARSAT-1 image and Leg 1 to 3 co-ordinates were in the general vicinity of the oil slick. Figure 7-13 provides an example of how the flight co-ordinates (shown as red squares) coincide with the slick on the SAR image. Leg 1 was 6 km from the closest point on the oil slick in the RADARSAT-1 image. Leg 2 was 17 km and Leg 3 was 32 km from the closest point on the oil slick in the image. These discrepancies are well within the 750 km positional accuracy of RADARSAT-1. This illustrated the positional discrepancies between the SAR image and the aircraft's GPS, which is less than a meter or a few meters accuracy and comparable to military standards. The RADARSAT-1 accuracy is reported in the RADARSAT Handbook. There is no documentation of the aircraft's GPS accuracy in any of the government reports.



(© Provincial Airlines Limited, 2002)

Figure 7-12 Canadian Coast Guard flight report with oil sightings circled and SAR image coverage

The SAR image is quite useful to initially locate an illegal oil slick. The first flight segment from the aircraft surveillance mission appeared to be a similar shape as the oil slick in the SAR image, and oil was located along several sections (See Figure 7-12). Based on the temporal difference of 5.5 hours between the acquisition of the SAR image and the aircraft arriving at the potential slick location, the slick appeared to be in smaller segments. This is typically the occurrence of slick dynamics where the long linear slick is broken up by wind and waves after the initial release (Bonn Agreement, 2004). A continuous slick usually breaks into fragments and windrows mainly due to the surface currents and turbulence (ITOPF, 2001). The 35 knots or 18 m/s wind speed on that morning may have displaced the oil after the SAR image was taken. This environmental effect on the oil slick is visible on the aerial photographs. The four separate slicks were an outcome of the natural weathering process of oil on the ocean.

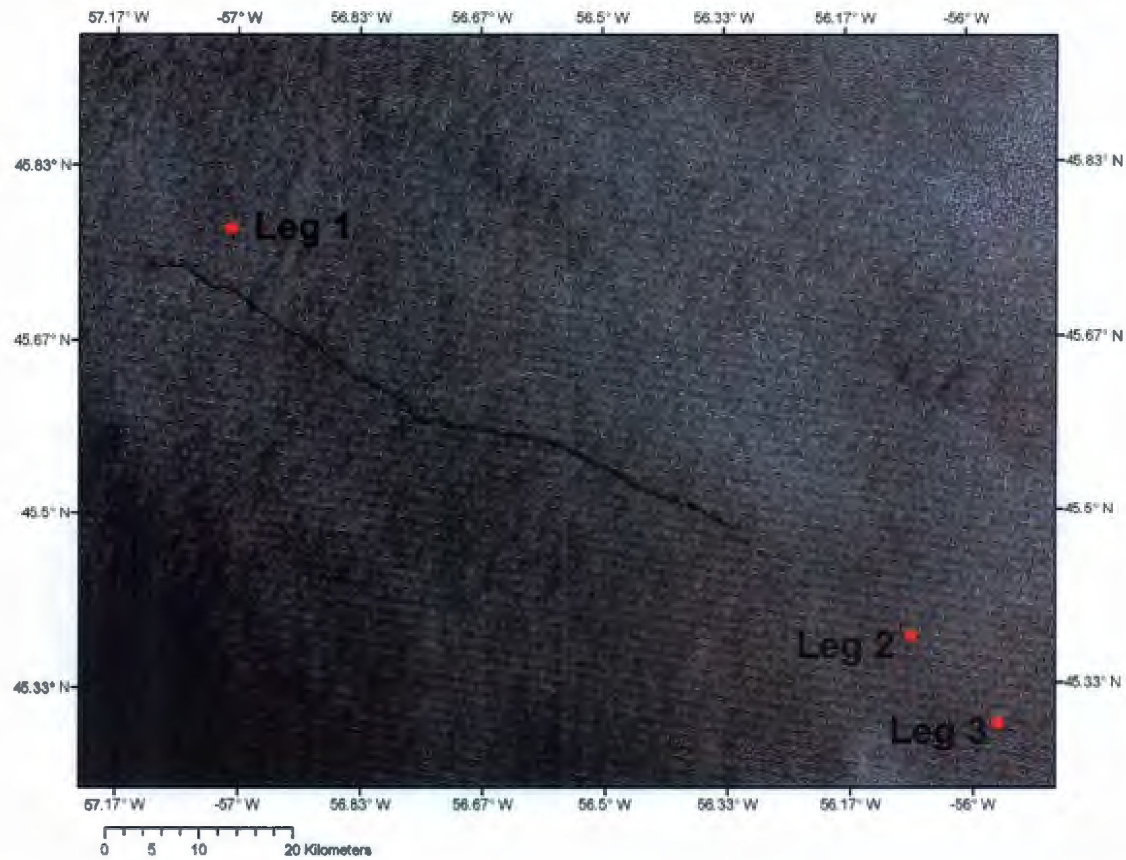


Figure 7-13 Aircraft GPS three oil sightings (red squares) with potential oil slick on SAR image

7.6 SAR Legal Preparation

Following the validation of the oil slick, the SAR image was prepared for legal use. Guidelines on the legal use of vertical and oblique aerial photographs were applied to the SAR image, and a template was designed for an expert witness to use in court. The suggested materials for presentation in court involve the creation of a SAR map product and a document detailing the information that would be required in court.

7.6.1 SAR Map Product

When a SAR image is presented in court as evidence of illegal ship discharges, the combination of the radar image with the oblique photographs in a graphic or map must be shown in order to increase the visual comprehension of the radar image. A map with the aerial photographs spatially referenced in the same co-ordinate system can illustrate the alignment of the image with the photographs. This map product, showing both corresponding oblique aerial photographs from the validation of the oil slick can help prove a case and determine whether an oil slick actually occurred, and that the photographs were not tampered with. The map product, Figure 7-14, illustrates how the oblique aerial photographs taken from these flight points overlap the SAR image. The flight report states that the oil spills were verified at all four locations. The admissibility and authenticity of the aerial photographs is strengthened by having their respective geographic co-ordinates printed on the photographs as they were being recorded during the flight. The map product design is based on aerial photograph guidelines, including labeling and other metadata information, such as satellite sensor name, acquisition date, imagery source, geographic location, and graphic scale.

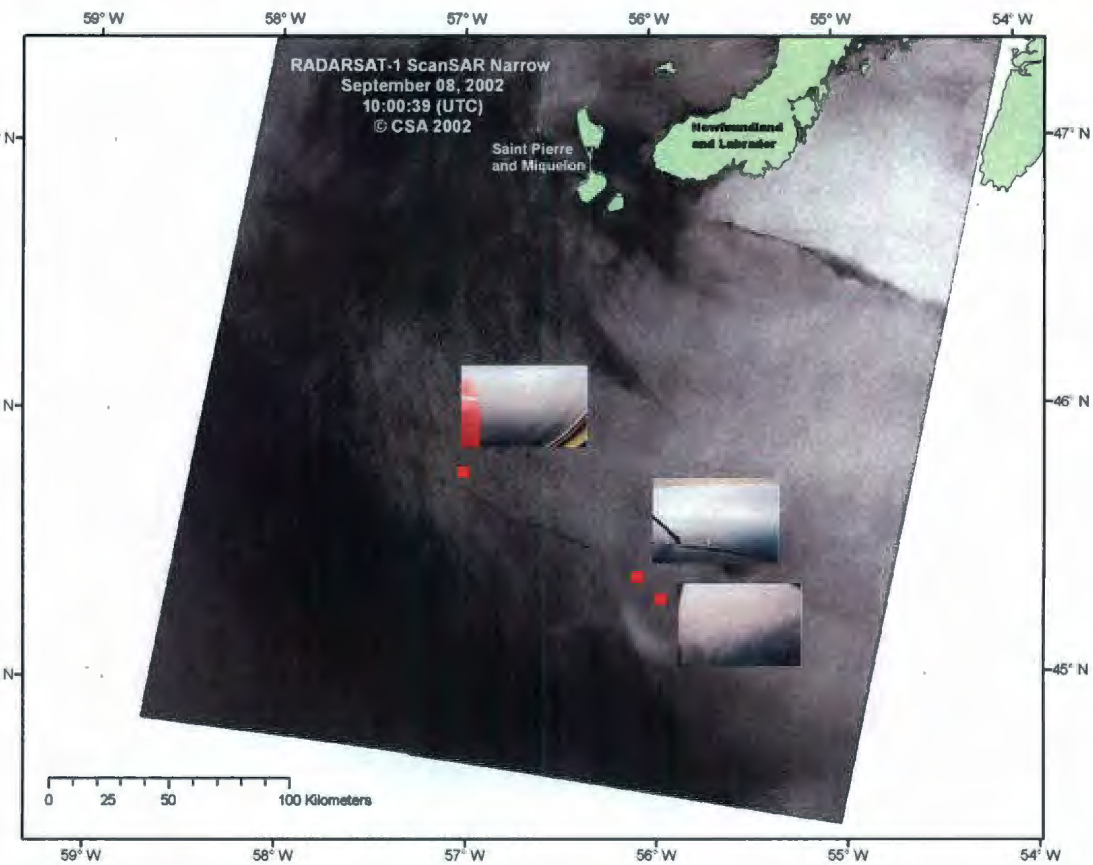


Figure 7-14 SAR map product for legal use

7.6.2 Expert Witness Procedure

There are many steps that the expert witness should follow when presenting SAR imagery in court for illegal oil discharges. The process of using a SAR image for the oil slick detection begins when the image is delivered to the remote sensing analyst. As illustrated in the case study, the handling and analysis are normally in several steps.

Firstly, the original RADARSAT-1 image was received and downloaded on a computer. The same computer is then used to view the image and create the oil spill map (Figure 7-14). Secondly, the image is imported into a remote sensing software package and displayed in order to interpret the image and identify any potential oil slicks. The geographic orbit co-ordinates included with the image were applied and then transferred to GIS software and viewed with other geographic data to verify the location accuracy. The image is imported and exported in different software packages and visually checked. The digital processing steps applied to the image were image calibration, which involved the conversion of digital numbers to beta nought values. Thirdly, the image is visually examined for potential oil slicks using the image interpretation elements that are an accepted method within the remote sensing scientific community. They include location, tone, size, shape, texture, volume, site and association, and use of collateral data. The validation of the image using the aerial photographs can now be shown using the map. This map or oil slick product and the original satellite SAR image should be copied on a CD, and processing notes from a logbook should be photocopied. This CD should be kept in a secure location, which limits access and ensures the custody and authentication of the evidence.

Other image metadata and legal guidelines from aerial photographs that must be applied to the presentation of SAR imagery in court are outlined in Table 7-3. The information should be described in court and in the form of a concise document when presenting SAR imagery. Therefore, the template contained in Table 7-3 was designed to be used, along with the map product presented in Figure 7-14, as a guide by an expert witness when presenting SAR imagery as evidence in court for illegal ship discharges. There are no set qualifications that are required for an expert witness. It is also recommended, as taken from aerial photographs legal guidelines that a computer print out of the map should be enlarged to one full page (8.5" * 11") and a photocopy of all analysis notes should be made. These documents should be dated and initialed.

Table 7-3 Template designed for SAR legal use in prosecuting oil discharges

Name, Address and Occupation: CV may be required to be submitted to court prior to the case
Satellite Platform and Sensor, Image Mode: Provide name of satellite and specifics about sensor and image or beam mode
Incident angle: Angle in degrees from nadir
Acquisition Time: Coordinated Universal Time
Chronological summary of the image interpretation report: Annotated interpretation based on standard interpretation elements as shown in Figure 6-1. Use Figure 7-2 as a basis of how to explain remote sensing process
Geographic Location: Provide latitude and longitude and UTM co-ordinates
Dimensions of oil slick: Provide an estimated length, width, area, and volume and show work that was performed
Wind speed and direction and Sea State: Provide wind speed and direction
Data Security: Explain chain of custody (i.e. copied on CD, dated, labeled and initialed and put with other evidence in locked cabinet)
Additional Notes: Describe data used for the validation of the satellite image

8 DISCUSSION

Since 1968, aerial photography has been the main remote sensing tool for detecting oil slicks, and has proven effective in many prosecutions for illegal ship discharges in Canadian waters (Armstrong, 2007). The quality of photography is negatively affected by environmental and atmospheric conditions, such as sunlight (glint and glare), fog, haze, cloud cover and darkness. If the proper conditions are not present, an aircraft based observer cannot identify an oil slick on the ocean's surface. An aircraft can be deployed in several hours to investigate a potential oil slick, but only a small area can be viewed at one time. The colour schemes of oil slick features in aerial photography can also be used to calculate volume estimates restricted to the dimensions of the photograph.

However, there are many benefits of using SAR images for the initial detection as well as an aid in the prosecution of oil discharges and they offer many advantages over solely using aerial surveillance. SAR is an active remote sensing system that operates in the microwave region of the electromagnetic spectrum and therefore has the capability to penetrate cloud and fog, darkness and light rain and snow, which are frequent occurrences in ocean and coastal environments. These characteristics make SAR an ideal candidate for oil slick detection on the ocean's surface and increase the chances of detecting illegal activities at sea, given that most illegal ship dumping occurs at night (Wiese, 2002). RADARSAT-1 imagery, similar to aerial photography, can be delivered within hours after data acquisition by the satellite where time is critical. Faster delivery times have been achieved under special circumstances, as in the case of oil spills. The location of the satellite images is dependent on the satellite's orbit. The availability of data from earth observation satellites offers the possibility to optimize surveillance strategies by providing coverage over areas not easily surveyed with aircraft. SAR can act as an early warning system in the detection of oil slicks as demonstrated in this case study and presented in Section 7. Therefore, there are many benefits to using both aerial photography and SAR imagery in the identification of oil discharges.

Discrepancies between the legal requirements and remote sensing capabilities include factors such as the specific accuracy level that is required to prove the reliability of evidence accepted in court. By using validation data from aerial photography, Brekke and Solberg (2005) achieved a classification accuracy of 88% in a SAR image. However, the degree of accuracy that is required by the legal community is not specified in the literature (Latin et al., 1976).

The demonstrative or operational use of a method does not mean the same thing in the remote sensing and legal community. Thus, there is an uncertainty of what these terms mean to each discipline. The legal literature states that "enhance" means the original image is changed while this means something different to the remote sensing community where there are many different types of enhancements (Marks, 1989). Most visual enhancements can be performed for display purposes without changing the original image because they use the information an image contains rather than creating new information. Visual and permanent enhancements mathematical functions can be documented as part of the metadata, and most enhancement equations can be back transformed to fit the initial image.

The authentication of oblique aerial photographs and SAR imagery for the detection of illegal oil discharges has been outlined by using the standard accepted image interpretation methods to identify of oil slicks. Three reference handbooks are currently used when attempting to visually identify oil slick from an aircraft, which include Transport Canada's *Standard Operating Procedures for Pollution Prevention Officers During Aerial Surveillance Missions* (Transport Canada, 2007), the *Bonn Agreement Aerial Surveillance Handbook* (Bonn Agreement, 2004) and the *International Tanker Owners Pollution Federation* (ITOPF) *Technical Information Paper: Aerial Observation of Oil* (ITOPF, 2001). These technical handbooks use the same techniques in the visual detection of oil. However, the *Bonn Agreement* handbook is the most detailed and provides useful colour photographs as illustrations. During the research for this thesis, the *Bonn Agreement's* colour classes were used to classify the oblique photographs to identity the presence of oil and to determine if they corresponded with the CCG visual interpretation. This, in turn, proves that CCG followed a standard procedure during the *McHugh* ship incident on September 08, 2002.

In this visual interpretation process, the photographs were not enhanced, and the only information extracted was oil features and ships. The standard accepted practice within the scientific community for the visual detection of oil slicks from aerial surveillance was used in the examination of this ship incident. However, the environment parameters of wind speed, visibility, sun angle and viewing angle were not properly documented.

When using SAR imagery, the same image interpretation elements for oblique aerial photographs are used in the visual identification of oil discharges. The only difference is the fact that SAR does not use colour in the identification of oil slicks, because the SAR produces a single band image. The authentication of SAR imagery has been demonstrated, where the original image was not altered during any processing step. In addition, the important factors that affect SAR oil slick detection, such as the beam mode and wind speed, were documented. There are no operating handbooks for SAR slick detection, but there are many peer-reviewed papers published on the standard method and parameters needed for such detection.

The admissibility of aerial photographs and SAR in the identification of illegal discharges was also proven. As for aerial photographs, the expert witness could be the PPO and for SAR, the remote sensing analyst who performed the image interpretation. In addition, the reliability of the technology was demonstrated, where both forms of remote sensing have progressed from an experimental state to an operational use. However, the main difference between aerial surveillance and SAR imagery is that aerial surveillance has been used operationally for a much longer period, and satellite SAR has only become operational in some countries over the last five to ten years. SAR imagery is only operational when used with aerial surveillance as the validation source.

From a technical perspective, there are no substantial differences in the ability to visually interpret oil using aerial photographs and SAR imagery. With regard to the authentication and admissibility of both remote sensing devices, there are no significant differences. When a remote sensing analyst creates a product, they are only extracting information from the imagery, and the original raw imagery does not change. However, there are some characteristics of the remote sensing techniques that are different. This includes the fact that, unlike an aerial photograph, SAR imagery does not operate in the visible spectrum. The legal use of SAR imagery was illustrated by using the RADARSAT-1 image from the *McHugh* ship incident and required legal guidelines set out by the legal community for aerial photographs. The flight report and other government reports establish the authenticity of standards and metadata practices. However, when used as legal evidence, there needs to be more consistency between the documents and there cannot be missing information in these reports.

While the SAR image interpretation procedure was reviewed, other steps that are typically used during SAR analyses were also evaluated to determine which steps might help or hinder the legal use of SAR imagery. The calibrated values were used for visual interpretation, and a geometric correction was performed on the image. Filtering techniques were applied to the image to illustrate that these techniques do not change the information content in the image. The validation of the SAR image is also shown and it is important that the aerial photos' co-ordinates match up with the slick identification on the

SAR image. The legal use of oblique aerial photographs and satellite SAR imagery requires that electronic reports used in court have the same formats or measurement units for photos and imagery. The main purpose for aerial photographs is to validate the oil slick identified on the satellite imagery and increase the visual comprehension of the facts being presented in court. Hence, a graphic, the final map product, was developed showing the correspondence between both remote sensing techniques. The steps of the analysis are summarized in a template or a set of procedures to use when going to court. This template helps to prepare the validation of SAR slick detection for legal use as evidence and can be used in conjunction with the map product when presented in court. The previously described procedure meets all of the legal requirements.

When presenting the map product and report in court, every processing step that was used in the creation of the product must be documented in a log book. Thus, the remote sensing analyst is more prepared, and photocopies of notes can be made for presentation in court. Traditionally, the training for remote sensing analysts recommends the use of a log book to document each processing step, which can be applied to multiple images. The enlargements of graphics are another legal guideline stated for aerial photographs' legal use. These enlargements can also be applied to the map product. The processing techniques of the SAR image could have been performed on digital aerial photography, including enhancements. The final product presented as evidence in court is in analog form. Considering computers are not readily available in court proceedings, it is more difficult to present digital products.

A further step in the validation of SAR is that the eye witness, such as the PPO on board the surveillance flight, verifies the presence of oil at a specific location. In this case, the photographs would be used as supporting evidence and explained by the witness. It is better to have photographs that have co-ordinates directly printed on them, such as the ones captured with a digital camera, which are also available on other government surveillance aircrafts. There are no geographic co-ordinates associated with each photograph. The only manner in which to match some of the oblique photographs to the SAR imagery is to use the co-ordinates provided with each oil sighting on the flight report and the chronological numbering printed on the back of each photograph.

The transition from oblique aerial photographs to SAR imagery as a source of remote sensing data available to the court of law has been presented in this study. Because it is based on a digital data type and imagery exploiting a non-visible spectral band, the application developed through the SAR imagery can be extended to imagery recorded by a number of other sensors capable of successfully identifying oil slicks. Some of these include ultraviolet, infrared thermal sensors and fluorosensors. The National Aerial Surveillance Program has incorporated new equipment onboard their aircraft to increase the reliability and accuracy of oil identification. This includes a Side-Looking Airborne Radar, an ultraviolet/infrared line scanner, an Airborne Automated Identification System transponder for receiving ship identity information, a high-resolution digital photography camera and video system with GPS data annotation, and a data processor interface that integrates all systems into one user console (Transport Canada, 2004).

In addition to these new aerial surveillance sensors, greater reliance on satellite data is possible with the launch of other SAR satellites, such as ENVIronment SATellite, and recently, RADARSAT-2. These satellites provide a higher spatial resolution of 3m for RADARSAT-2 and better temporal resolution, where multiple satellites can be used to collect more images over a particular area. These satellites will provide more detail with higher spatial resolution on oil spills and the ability to monitor them more frequently.

9 CONCLUSION

The parameters for the admissibility of visual aids as evidence were identified in the legal literature. There are no legal barriers for using oblique aerial photographs and SAR imagery as evidence, considering both are admissible in court when the competency of the expert witness and the reliability of the data have been established. During this research, it was also shown that an expert witness must be able to explain the SAR image interpretation to the court. An expert witness must be qualified and demonstrate their expertise, accomplishments, and recognition by their peers. The reliability of SAR slick detection was presented by compiling the peer-reviewed research that continually applied the same technique with the same parameters. This shows the acceptance of SAR slick detection within the remote sensing discipline.

A case study using a SAR image and high oblique aerial photographs from a pollution incident off the coast of Newfoundland demonstrated that these data could be used to help identify and potentially prosecute an illegal oil discharge. The technological parameters for the validation of SAR imagery were applied by using oblique aerial photographs to verify an alleged oil slick. The visual image interpretation processes are identical for both data types. Therefore, if oblique aerial photographs were accepted as evidence in court, then SAR imagery can also be used. The authentication of the oblique aerial photographs and SAR imagery as evidence was demonstrated through the case study by outlining the accepted image interpretation process and applying the existing legal and metadata standards.

From a scientific remote sensing perspective, there are no reasons for satellite SAR not to be used as evidence to prosecute illegal oil discharges, in conjunction with aerial surveillance photographs. In terms of the admissibility and authentication of both remote sensing technologies, there are minimal differences. Hence, one would question why satellite SAR has been so little used as legal evidence. An explanation is that SAR records imagery from the microwave portion of the electromagnetic spectrum and not in the visible. The radar backscattering is not necessarily correlated with the visible reflectance and for this reason the interpretation of the radar image is more difficult to people unfamiliar with radar technology.

Another reason might be that aerial photographs have been used operationally since the 1960s in contrast to SAR imagery which has only been used since the early 1990s. Therefore, the technology is seen as new, and not enough is known about SAR imagery in the general public and the legal community, including lawyers and court judges who may be reluctant to use new technology as evidence. Previously, when other new technologies are first introduced, such as the first surveillance video case, it only took one judge to accept it as evidence and set a precedent. To date, there has not been one case in a Canadian court where satellite SAR has been used as evidence, although the literature review has shown use in other jurisdictions. This research shows that there are no technical reasons why satellite radar imagery cannot be used for evidence in the illegal discharges of oil from ships in Canadian waters.

REFERENCES

Alpers, W. and Huhnerfuss, H. (1989) The Damping of Ocean Waves by Surface Films: A new Look at an Old Problem. *Journal of Geophysical Research* vol. 94, p. 6251 – 6265.

Armstrong, L. (2007) The Canadian Experience. SPILLCON Response Issues Seminar, *11th International Oil Spill Conference*. March 30, 2007.

Benidickson, J. (2002) *Environmental Law*, Irwin Laws Inc., Toronto, 2nd Edition.

Bern, T.-I., Moen, S., Wahl, T., Anderseen, T., Olsen, R. and Johannessen, J.A., (1992) Oil Spill Detection using Satellite based SAR: *Compilation Report for Phase 0 and 1. Technical Report, OCEANOR Report No. OCN-R92071,* Trondheim.

Bern, T.-I., Washi, T., Anderseen, T. and Olsen, R (1993). Oil Spill Detection- Using Satellite Based SAR: Experience from a field experiment. *Photogrammetric Engineering and Remote Sensing,* vol. 59, no. 3 p. 423-428.

Bonn Agreement (2004) *Bonn Agreement Aerial Surveillance Handbook.*

Brekke, C. and Solberg, A. (2005) Oil spill detection by Satellite Remote Sensing. *Remote Sensing of Environment*, vol. 95, p. 1-13.

Canadian Coast Guard (2002a) *Canadian Coast Guard Incident Report # 300-11-07*, Canadian Coast Guard, Newfoundland and Labrador Region, Canada, 10p.

Canadian Coast Guard (2002b) *Canadian Coast Guard Marine Pollution Incident - Situation Report N2002-0112,* Canadian Coast Guard, Newfoundland and Labrador Region, Canada, 10p.

Canadian Legal Information Institute (CanLII) (2007) http://www.canlii.org/

Canada Evidence Act (1996) http://www.qp.gov.bc.ca/statreg/stat/E/96124_01.htm

Canada Shipping Act (2001) http://laws.justice.gc.ca/en/showdoc/cs/C-5///en?page=1

Colwell, R. (1997) History and Place of Photographic Interpretation, *Manual of Photo Interpretation*, W. Philipson, (Ed), 2nd Ed, Bethesda, ASP & RS, p. 3-48.

Committee on Earth Observation (CEOS) (2007) www.ceos.org

Committee on Oil in the Sea (2003) Oil in the Sea III: Inputs, Fates, and Effects, National Research Council, National Academy Press. Washington, D.C., USA. 265p.

Cox C. and Munk, W. (1954) Measurement of the Roughness of the Sea Eurface from Photographs of the Sun's Glitter. *Journal of Optical Society of America,* vol. 44, p. 838-850.

Curley, P. (2005) GIS Litigation Support Applications in the Courtroom. *Proceedings of the Twenty-Fifth Annual ESRI User Conference*, San Diego, California, USA, 2005.

Curran, P. (1987) Remote Sensing Methodologies and Geography. *International Journal of Remote Sensing,* vol. 8, no. 9, p. 1255-1275.

Dams, R., Fitze, L. and Lane, E. (1986) Colour Infrared Aerial Photography for Herbicide Drift Damage Assessment. *Proceedings of the Tenth Canadian Symposium on Remote Sensing, Edmonton, Alberta*, vol. II, p. 639-595.

Davies, C., Hoban, S. and Penhoet, B. (1999) Moving Pictures: How Satellites, The Internet, and International Environmental Law can help Promote Sustainable Development. *Stetson Law Review*, vol. 28, p. 1091-1153.

DeAbreu, R., Gauthier, M-F. Van Wychen, W. (2006) SAR-based Oil Pollution Surveillance in Canada: Operational Implementation and Research Priorities. *Proceedings of OceanSAR 2006 – Third Workshop on Coastal and Marine Applications of SAR,* St. John's, NL, Canada, October 2006.

Duncan I. (2003) Negligence and Professional Malpractice related to GIS datasets. *Digital Mapping Techniques '03 Workshop Proceedings*, U.S. Geological Survey Open-File Report 03-471, p.41-45.

Electronic Frontier Canada (1982) Canadian Charter of Rights and Freedom http://www.efc.ca/pages/law/charter/charter.text.html

Environment Canada (2002) *National Environmental Emergencies System (NEES) Incident Report # 22860*, Environment Canada, Newfoundland and Labrador Region, Canada, 2p.

Espedal, H. (1998) Detection of Oil Spill and Natural Film in the Marine Environment by Spaceborne Synthetic Aperture Radar. PhD thesis, Department of Physics University of Bergen and Nansen Environment and Remote Sensing Center, Norway.

Estes, J, Hajic, E. and Tinney, L. (1983) Fundamentals of Image Analysis: Analysis of Visible and Thermal Infrared Data, *Manual of Remote Sensing,* R.N. Colwell, (Ed), Bethesda: ASP & RS, vol. 1, p. 1039 -1040.

Fadaie, K., de Rijcke, I. and Slade, S. (2001) Geospatial Information as a tool in Legal Dispute Resolution, *Geomatica*, vol. 55, no.11, p. 79-89.

Feigels, V. and Kopilevich, Y. (1996) *Laser Remote Sensing of Natural Waters: From Theory to Practice*, Proceedings SPIE, vol. 2964, p. 26-37.

Fiscella, B., Giancaspro, A., Nirchio, F., Pavese, P. and Trivero, P. (2000) Oil Spill Detection using Marine SAR Images. *International Journal of Remote Sensing*, vol. 21, no.18, p.3561-3566.

Fisheries Act (1985) http://laws.justice.gc.ca/en/showdoc/cs/F-14//20090126/

Fusco, L. and Vizzari, S. (1998) Pre-Operational Oil Pollution Monitoring and Forecast in the Mediterranean Sea using Satellite Data. *17th International Conference on Offshore Mechanics and Arctic Engineering (ASME)*, July 1998, Lisbon, Portugal.

Geer, K. (1991) The Constitutionality of Remote Sensing Satellite Surveillance in Warrentless Environmental Inspections. *Fordham Environmental Law Report*, vol. 3, p 43-56.

Gillen, L. (1986) Photographs and Maps Go to Court. *American Society of Photogrammetry and Remote Sensing Session on Forensic Photogrammetry,* March 16th during the ASPRS-ACSM Annual Convention in Washington, D.C. 67p.

Ginzky, H. (2001) Satellite Images as Evidence in Legal Proceedings Relating to the Environment –A U.S. Perspective. Droit et Ville, vol. 51, p.37-68.

Goodman, R. (1994) Overview and Future Trends in Oil Spill Remote Sensing. *Spill Science and Technology Bulletin*, vol. 1, no.1, p. 11-21.

Hollinger, J. and Mennella, R. (1984) Measurement of the Distribution and Volume of Seas-surface Oil Spills using Multi-frequency microwave Radiometry. *Remote Sensing for the control of marine pollution*, Edited by Jean-Marie Massin, NATO Challenges of Modern Society, vol. 6, Plenum Press.

Hovland, H., Johannessen, J. and Digranes, G. (1994) Slick detection in SAR images, *Proceedings of IGARSS 1994, Surface and Atmospheric Remote Sensing: Technologies, Data Analysis and Interpretation,* Pasadena, California, USA, vol. 4, p. 2038-2040.

Huhnerfuss, H., Alpers, W., Linwood Jones, W., Lange. P. and Richter, K. (1981) The damping of Ocean Surface Waves by a Monomolecular film measured by Wave Staffs and Microwave Radars, *Journal of Geophysical Research,* vol. 86, p. 429-438.

ITOPF (2001) ITOPF (International Tanker Owners Pollution Federation Limited), Technical Information Paper: *Aerial Observation of Oil*, International Tanker Owners Pollution Federation, London, UK, 8p.

Ivanov, A., He, M. and Fang, M. (2002) Oil Spill detection with the RADARSAT SAR in the waters of the Yellow and East China Sea: A case study. *Proceedings of the Asian Conference on Remote Sensing (ACRS).*

Jensen J. R. (2005) *Introductory Digital Image Processing: A Remote Sensing Perspective.* Toronto. Pearson Education Canada, Ltd. Third Edition, 525p

Jensen J. R. (2007) *Remote Sensing of the Environment: An Earth Resource Perspective.* Toronto. Pearson Education Canada, Ltd. Second Edition, 592p.

Johannessen J., Shuchman R., and Johannessen O. (1994) Mesoscale Variability Studies with SAR on ERS-1, *Oceanographic Applications of Remote Sensing*, edited by Ikeda M. and Dobson F., CRC Press Inc., Boca Raton.

Johannessen, O., Espedel, H., Jenkins, A., and Knulst, J. (1995) SAR Surveillance of Ocean Surface Slicks, *Proceedings of the Second ERS Applications Workshop*, London, UK, December 6-8, 1995.

Jordan, R. and Payne, J. (1980) *Fate and Weathering of Petroleum Spills in the Marine Environment,* Edition Ann Arbore Science- The Butterworth Group, p. 4.

Kelly, M., Estes, J. and Knight, K. (1999) Image Interpretation Keys for Validation of Global Land-Cover Data Sets, *Photogrammetric Engineering & Remote Sensing,* vol. 65, p. 1041 - 1049.

Konecny, G. (2003) *Geoinformation: Remote Sensing, Photogrammetry and GIS*, London: Taylor & Francis, 189 p.

Konings, H. (1996) Oil Pollution Monitoring on the North Sea. *Spill Science & Technology Bulletin*, vol. 3, no. 1, 2, p. 47- 52.

Krowse, A.J., Ferry, M.W., and Crowsey, R.C. (2000) Satellite Imagery: The Space Odyssey Arrives in the Courtroom. http://www.crowsey.com/spacearticle.htm

Latin, H. A., Tannehill, G. W. and White, R.E. (1976) Remote Sensing Evidence and Environmental Law, *California Law Review,* vol. 64, no. 6, December, p.1300-1446.

Le Chevalier, F. (2002) *Principles of Radar and SONAR Signal Processing*, Artech House, Norwood, MA, 397 p.

Lee, J. (1980) Digital Image Enhancement and Noise Filtering by Use of Local Statistics", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAM1-2, no. 2, March.

Lehr, W. (1994) Oil Spill Monitoring using a Field Microcomputer - GPS Receiver Combination, *The Second Thematic Conference on Remote sensing for Marine and Coastal Environments,* New Orleans, Louisiana, USA, January 31, 1994.

Lillesand, T. and Kiefer, R. (2000) *Remote Sensing and Image Interpretation.* Toronto. John Wiley & Sons, Inc. Fourth Edition, 724 p.

Liping, D. (2003) The development of Remote-Sensing Related Standards at FDGC, OGC and ISO TC 211, *IEEE International Geoscience and Remote Sensing Symposium*, Toulouse, France, July 21-25, 2003, vol.1, p.643-647.

Lopes, A. Touzi, R. and. Nezry, E. (1990) Adaptive Speckle Filters and Scene Heterogeneity, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 28, no. 6, November, p. 992-1000.

Markowitz, K. J. (2002) Legal Challenges and Market Rewards to the Use and Acceptance of Remote Sensing and Digital Information as Evidence. *Duke Environmental Law and Policy Forum*, vol. 12, Spring, 2002, p 219- 264.

Marks, B.S. (1989) Dispute Resolution in the Space Age: Forensic Applications of Earth Observation Satellite Data through Adaptation of Technical Standards similar to DNA Fingerprinting Protocols, *Journal of Dispute Resolution*, vol.5, no.1, p. 19-73.

Martinez, A. and Moreno, V. (1996) An Oil Spill Monitoring System based on SAR images. *Spill Science and Technology Bulletin*, vol. 3, no. 1, 2, p.65-71.

McGlone, J. (2004) *Manual of Photogrammetry,* 5th Ed. Bethesda: ASP&RS, 1151 p.

MDA (2002) *MacDonald Dettwiler and Associates Geospatial Service's (MDA) Oil Slick Report* 35727_01, MDA, Quebec, Canada, 1p.

Migratory Birds Convention Act (1994) http://laws.justice.gc.ca/en/showtdm/cs/M-7.01

Oil Spill Hazard Team (1997) *Interim Report of the Oil Spill Hazard Team*, p. 62-69.

O'Neil, R., Neville, R. and Thomson, V. (1983) *The Arctic Marine Oil Spill Program (AMOP) Remote Sensing Study*. Minister of Supply and Services Canada. En 46-4/83-3E. 257 p.

Paciocco D.M. and Stuesser, L. (1999) *The Law of Evidence*. Third Edition, 494 p.

Paulsson, J. (2001) Boundary Disputes into the Twenty-First Century Why, How…Who? *American Society of International Law Proceedings,* vol. 95, p.122-128.

Pavlakis, P., Tarchi, D. and Sieber, A.J. (2001) On the Monitoring of Illicit Vessel Discharge using Spaceborne SAR Remote Sensing- A Reconnaissance Study in the Mediterranean Sea, *Annals of Telecommunications,* vol. 56, no 11-12, p.700-718.

Pedersen, J., Seljelv, L., Strm, G., Follum, O., Andersen, J., Wahl, T. and Skoelv, A. (1996) Oil spill detection by use of ERS SAR data; from R&D towards Pre-operational Early Warning Detection Service, *Proceedings of the Second ERS Applications Workshop*, London, ESA SP-383, ESA Publications Division, The Netherlands.

Pellemans, A. Bos, W., van Swol, R., Tacoma, A. and Konings, H. (1995) Operational use of Real-time ERS-1 SAR data for Oil Spill Detection on the North Sea: First Results. *Proceedings of Second ERS-1 Symposium*, Space at the Service of our Environment, ESA SP-361, p. 425–430.

Perez-Marrodan, M. (1998) ENVISYS – Environmental Monitoring Warning and Emergency Management System. *Proceedings of the AFCEA Kiev Seminar,* May 28 - 29, p. 122-132.

Petrocchi, A. (2000) Slick Sensing. Monitoring Oil Spills with Satellite Imagery, *Geo Info Systems*, May, p. 32-36.

Polet, M., Dams, R.V. and Wells, J. (1986) Sulphur Dioxide Assessment using Colour Infrared Aerial Photography. *10th Canadian Symposium on Remote Sensing*, Edmonton, Alberta, vol. 2, p. 855-860.

Quinn, A. (1979) Admissibility in Court of Photogrammetric Products. *Photogrammetric Engineering and Remote Sensing*, vol. 45, no. 2, p. 167-170.

RADARSAT International (1995) *RADARSAT-1 Handbook: Guides to Products and Services.*

RADARSAT International (2000) *RADARSAT Data Products Specifications*, Reference Number, RSI-GS-026.

Raney, R., Luscombe, A., Langham, E. and Ahmed, S. (1991). RADARSAT, *Proceedings of the IEEE*, vol. 79, no. 6, p. 839-849.

Raney, R.K., Freeman, T., Hawkins, R.W. and Bamler, R. (1994) A Plea for Radar Brightness. *Proceedings of IGARSS 1994, Surface and Atmospheric Remote Sensing: Technologies, Data Analysis and Interpretation,* Pasadena California, USA, vol. 2, p. 1090-1092.

Reeves, R. G., Anson, A. and Landen, D. (1975) Manual of Remote Sensing. *American Society of Photogrammetry*, Falls Church, vol. 2. 2144 p.

Robinson, I. and Ufermann, S. (2003) Data Validation and Model Verification Within MARSAIS, *MARSAIS Report No. D16/2003/1*, December, p. 2-30.

Singh, K. (1995) Monitoring of Oil Spills using Airborne and Spaceborne Sensors. *Advanced Space Research*, vol. 15, no. 11, p.101-110.

Smith, S.J. (1996) Thermal Surveillance and the Extraordinary Exception: Re-Defining the Scope of the *Katz* Analysis. Valparaiso *University Law Review*, vol. 30, p. 1071-1117.

Sopinka, J., Lederman, S.N. and Bryant, A.W. (2004) *Law of Evidence in Canada*, Edition supplement 394 p.

Standards Council of Canada (2000) *Summary of Corporate Plan*, Ottawa, Ontario, p. 65.

Supreme Court of Canada (2007) http://csc.lexum.umontreal.ca/en/

Taft, G., Egging, D. and Kuhn, H. (1995) Sheen Surveillance: An Environment Monitoring Program Subsequent to the 1989 Exxon Valdez Shoreline Cleanup. *Exxon Valdez: Oil Spill: Fate and Effects in Alaskan Waters,* ASTM 1219, American Society for Testing and Materials, Philadelphia.

Transport Canada (2004) New Equipment to Detect Ship Pollution, No. H126/04, December 17, 2004 http://www.tc.gc.ca/mediaroom/releases/nat/2004/04-h126e.htm

Transport Canada (2007) *Standard Operating Procedures* (SOPs) *for Pollution Prevention Officers During Aerial Surveillance Missions.* Transport Canada, Marine Safety, Newfoundland and Labrador Region, Canada, 7p.

Tschangho, J.K. (1999) Metadata for Geospatial Data Sharing: A Comparative Analysis. *The Annals of Regional Science*, vol. 33, p.171-181.

Tufte, L., Trieschmann, O., Hunsanger, T., Kranz, S. and Barjenbruch, U. (2002) *Using Air- and Spaceborne Remote Sensing Data for the Operational Oil Spill Monitoring of the German North Sea and Baltic Sea,* OCEANIDES GMES Project (EVK2-CT-2002-00177) Report, 5p.

Tufte, L., Trieschmann, O., Carreau, P., Hunsaenger, T., Clayton, P. and Barjenbruch, U. (2004) Development of an Oil Spill Information System combining Remote Sensing Data and Surveillance Metadata. *Proceedings of SPIE*, vol. 5239, p.72 -80.

Turpin, W. (2003) *I-STOP Final Report: Eyes in the Skies*. Environment Canada.

Van Kuilenburg, J. (1975) Radar Observations of Controlled Oil Spills, *Proceedings of the 10th International Symposium on Remote Sensing of Environment,* Ann Arbor, Michigan, October 6 - 10, p. 243–250.

Volckaert, F., Kayens, G., Schallier, R. and Jacques, T. (2000) Aerial Surveillance of Operational Pollution in Belgium's Maritime Zone of Interest. *Marine Pollution Bulletin,* vol. 40, no. 11, p.1051-1056.

Vachon, P. Thomas, S., Cranton, J., Bjerkelund, C., Dobson, F. and Olsen, R. (1998) Monitoring the Coastal Zone with RADARSAT satellite. *Oceanology International 1998*, UK, March 10-13, 10 pages.

Wahl, T., Anderssen, T. and Skoelv, A. (1994) *Oil Spill Detection using Satellite based SAR*, Pilot Operation Phase, Final report, Technical Report, Norwegian Defense Research Establishment.

Wiese, F. (2002) *Seabirds and Atlantic Canada's Ship-Source Oil Pollution,* World Wildlife Fund (WWF) Canada Report, September, p.6.

World Legal Information Institute (WorldLII) (2007) http://www.worldlii.org/

Wong, D.W.S. and Wu, V.C. (1996) Spatial Metadata and GIS for Decision Support. 29th Hawaii International Conference on System Sciences (HICSS) *Collaboration Systems and Technology*, vol. 3, p.557-566.

COURT CASES

ANR Production v. M/V Mekhanik
1989 A.M.C. 2299 (1989 S.D. Tex.)

Botswana v. Namibia
ICJ Reports 1996 (II), p. 812, para. 23

Chevron U.S.A. Inc. v. United States
658 F.2d 271 (5^{th} Cir. 1981)

Daubert v. Merrel Dow Pharmaceuticals
113 S. Ct. 2786 2798 (1993)

Dow Chemical Co. v. United States
476 U.S. 227 (1986)

Frye v. United States
293 F.1013 (D.C. Cir. 1923)

Gasser v. United States
14 Claims Court 476 (1988)

I&M Rail Link v. Northstar Navigation
21 F. Supp. 2d 849, 855 (N.D. Ill. 1998)

Qatar v. Bahrain
ICJ Reports 2001, para. 197

R. v. Mohan
(1994), 2 S.C.R. 9

R. v. Nikolovski
3 S.C.R. 1197, 1996 CanLII 158 (S.C.C.)

R. v. Tessling
R. v. Tessling, [2004] 3 S.C.R. 432, 2004 SCC 67 (CanLII)

State v. Inland Steel Company
No. 72 CH 259 (Ill. Cir Ct. Cook County) 1976

United States v. Reserve Mining Company
380 F. Supp. 11(D. Minn.1974)